TECHNICAL AND FINANCIAL FEASIBILITY OF ON-SITE TEA ORGANIC WASTE USAGE: A CASE OF TEA ESTATES IN MULANJE DISTRICT, MALAWI

MASTER OF SCIENCE IN ENVIRONMENTAL PROTECTION AND MANAGEMENT DISSERTATION

BEDAH MNJEZA

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Master of Science in Environmental Protection and Management Dissertation

By

BEDAH MNJEZA

BSc (Irrigation Engineering)

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DECLARATION

I, Bedah Mnjeza, declare that this Dissertation entitled ***"technical and financial feasibility of on-site tea organic waste usage: A Case of Tea Estates in Mulanje District, Malawi***" is my own work. It is submitted in partial fulfilment of the requirements for the Degree of Master of Science in Environmental Protection and Management at the University of Malawi. It has not been submitted for any degree or examination to any university or college.

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CERTIFICATE OF APPROVAL

The undersigned certify that they have read and approve for acceptance by the University of Malawi, this Dissertation entitled dissertation "***assessing the technical and financial feasibility of on-site tea organic waste usage: A case of tea estates in Mulanje district***, Malawi"

Main Supervisor: **Dr Khumbo Kalulu**

Signature: **…………………………………..**

Date: **..…………………………………**

Head of Department: Prof. Harold Mapoma

Signature: ……………………………………….

Date: ………………………………………..

Head of Postgraduate Studies: Ass. Prof. Rhoda Bakuwa

Signature: …………………………………………..

Date: …………………………………………..

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ABSTRACT

Hygienic waste disposal poses a significant challenge in developing countries, especially those with high population densities, such as Malawi. Inadequate waste management across all types (solid, liquid, and thermal) and from diverse sources impacts various industries worldwide, including agriculture, mining, and construction. The Tea industry in Malawi faces similar challenges due to inadequate waste management practices, particularly with regards to the organic waste generated from tea factories. Lack of knowledge on utilizing this waste has led to improper disposal in dumpsites. Additionally, the high costs associated with purchasing and applying inorganic fertilizers in tea fields have prompted the need to explore alternative waste management solutions. This study specifically aimed to assess the levels of NPK nutrients in organic tea waste and examine the financial feasibility of using it onsite in Mulanje District, Southern Malawi. Samples were collected from three tea estates in Mulanje District. The technical analysis focused on determining the nitrogen, phosphorus, and potassium content in the organic tea waste, as these are essential primary nutrients for plant growth. A financial analysis was conducted to evaluate potential cost savings if inorganic fertilizers were replaced or co-applied with organic waste. The study revealed that the average proportion of nitrogen in the organic tea waste was 3.19%, phosphorus was 0.58%, and potassium was 0.43%. These NPK nutrient contents were significantly lower than those found in chemical fertilizers (T-compound). The application rate of tea waste required to supply the same amount of nitrogen as chemical fertilizer (T-compound) was determined to be 1935 Kg/ha. Furthermore, the use of tea waste would result in total savings of 22.2% of the total cost of chemical fertilizer. The study provides evidence of the NPK nutrient levels in organic tea waste and highlights the financial feasibility of its onsite usage for tea production. To address the issue of poor waste management, it is recommended that tea factories focus on increasing the value of tea waste over time through industrial processing activities aimed at producing useful products or sources of energy, such as through reuse, recycling, or composting. By implementing these recommendations, the tea industry in Malawi can contribute positively to the country's economy while addressing environmental concerns related to waste management.

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ABBREVIATIONS AND ACRONYMS

3Rs	Reduce, Reuse and Re-cycle
ADB	African Development Bank
BOD	Biochemical Oxygen Demand
CBO	Community Based Organisation
CE	Circular Economy
CO	Carbon Monoxide
COD	Chemical Oxygen Demand
CTC	Crush, Tear and Curl
EU	European Union
FYM	Farm Yard Manure
K	Potassium
LAI	Leaf Area Index
LTP	Lawrie Tea Processor
Mg	magnesium
N	Nitrogen
NPK	Nitrogen, Phosphorus, Potassium
NUE	Nitrogen Use Efficiency
P	Phosphorus
S	Sulphur
SPSS	Statistical Package for Social Scientists
SSF	Solid State Fermentation
SWM	Solid Waste Management
TW	Tea Waste
Zn	Zinc

CHAPTER 1: INTRODUCTION

1.1. Study background

Solid waste management in the context of agricultural waste is a crucial challenge that extends beyond urban areas, particularly in developing countries. As indicated by Sichiweza (2017), waste generation rates often surpass the capacity for proper management in these nations. In Malawi, the growth of both population and economy has led to a significant increase in solid and liquid waste generation, making waste management a major problem (GoM, 2014). The agricultural sector, including the tea industry, is not exempt from this predicament. Similar observations have been made in Kenya, where waste management in tea industries has been problematic, with non-compliance with national regulations being common (Mutai, 2018; Oirere, 2015).

The lack of proper agricultural waste management options, such as reusing and recycling, is evident in tea factories in Malawi, where solid waste is often left in uncontrolled dumpsites (GoM, 2014). Such practices have negative consequences for soil, surface water, groundwater, and air, leading to contamination and posing threats to public health and the environment. Consequently, there is a pressing need for improved waste management strategies in the agricultural sector, including the tea industry, to mitigate these challenges.

Addressing agricultural waste management requires a comprehensive approach that includes prevention, minimization, collection, transportation, processing, recycling, and disposal, as defined by the Government of Malawi (GoM, 2014). While solid waste management in this context may be complex, there are opportunities for implementing sustainable waste management practices in the agriculture sector. For instance, adopting composting techniques can facilitate the conversion of organic waste, such as tea residues and other agricultural byproducts, into nutrient-rich compost. This compost can then be used to enhance soil fertility and reduce the reliance on chemical fertilizers. Additionally, exploring innovative techniques, such as bioenergy production from agricultural waste, can contribute to energy generation and reduce waste volumes (Liyala, 2011).

Collaboration between agricultural stakeholders, local authorities, and researchers is essential to develop and implement effective waste management strategies that align with national waste management policies. By addressing agricultural waste challenges through sustainable practices and embracing the opportunities for resource recovery and energy generation, Malawi's agricultural sector can make significant strides towards achieving better waste management practices, supporting soil fertility, and promoting environmental sustainability.

Recycling of plant nutrients in crop, factory, and human waste has been a traditional approach to maintain soil fertility (Schouw et al., 2003). However, with the advancements of the last century, the growing divide between urban and rural settlements has disrupted the recycling process. As a result, valuable plant nutrients are now being lost to the ever-increasing volume of urban waste instead of being reclaimed for agricultural soils (Schouw et al., 2003). The depletion of both nutrients and biodegradable material from agricultural soils affects the demand for higher crop yield to feed the increasing population in developing countries (Mutai, 2018; Schouw et al., 2003). In urban areas, the increasing amounts of unmanaged solid waste cause pollution and unhygienic conditions and yet there is potential that this waste can be recycled.

1.2. Problem statement

Malawi is facing significant challenges in agriculture waste management. According to a report by Chaguluka and Chiotha (2020), inadequate waste disposal infrastructure and limited awareness of sustainable waste management practices have led to the improper handling of agricultural residues. As a result, large quantities of tea wastes and other agricultural by-products end up in open dumping sites or burned openly, causing environmental pollution and health hazards. The lack of proper waste recycling systems hinders the country's ability to capitalize on the potential benefits of using agricultural residues as compost or bioenergy sources, contributing to soil degradation and loss of valuable resources.

According to the Malawi Tea 2021 Annual Report, tea production in Malawi has been steadily increasing in recent years. In 2020, the country produced a total of 63,805 metric tonnes of tea, representing a significant growth compared to previous years. This increase can be attributed to various factors, including expanded tea cultivation areas, improved farming practices, and investments in modern processing facilities. The rise in tea production reflects the growing importance of the tea industry in Malawi's economy and highlights the need for sustainable waste management solutions to address the accompanying increase in tea waste generation (Malawi Tea Annual Report, 2021). With the increase in the tea production and tea waste generation in the tea processing factories, there is need to explore the possibility of recycling the tea waste with the aim of being used in the tea fields and other crop fields as an alternative to the current inorganic fertilizers used. Furthermore, recycling tea wastes and agricultural residues brings numerous environmental, economic, and social benefits. It diverts these materials from landfills or incineration, reducing waste burden on the environment. Valuable organic matter, nutrients, and compounds in the wastes enhance soil fertility, reducing the need for synthetic fertilizers and conserving natural resources. Soil enrichment with compost or organic fertilizer improves structure, water retention, crop productivity, and reduces erosion. Recycling reduces greenhouse gas emissions caused by waste decomposition. It fosters a circular economy, creating a closed-loop system that promotes sustainability and minimizes reliance on external inputs. Some residues can be used for biomass energy generation, reducing fossil fuel reliance. Economic opportunities arise from innovative recycling processes, technologies, and products, fostering growth in green industries and job creation. While the use of inorganic fertilizers in agriculture to improve soil fertility and increase crop yields has immediate results, the escalating prices make it impossible for most smallholder farmers to use them (Msukwa et al., 2011). Furthermore, the overuse of chemical fertilizers recently generated some serious issues in the field of agriculture like hardening of soil, decreased fertility, strengthened pesticides, polluted air and water, and released greenhouse gases, thereby bringing hazards to human health and environment as well. In order avoid these problems use organic fertilizers playing key role as these are environment friendly, economical, non-hazardous (Patil et al. 2018). There is, therefore, need for alternative low-cost soil fertility enhancing technologies which organic compost manure seems to be a viable option to be promoted (Msukwa et al., 2011). However, there has been low adoption or use of organic compost manure. According to a study by Msiska et al. (2019), one of the main reasons is the limited access to quality compost materials and composting knowledge among farmers. Many farmers lack the necessary information and training on composting techniques and its benefits, leading to a preference for traditional methods or synthetic fertilizers. Additionally, the lack of proper infrastructure for compost production and distribution hinders its availability in rural areas, where most farming activities take place. Moreover, financial constraints has also deterred farmers from investing in composting as it requires initial costs and time for preparation. It is against this background that by assessing the nutrient composition and financial feasibility of using organic waste recycled from tea waste, it provides practical solutions that can transform agricultural waste management in Malawi. It also offers a pathway to enhance environmental sustainability, boost agricultural productivity, and improve the livelihoods of farmers, contributing to the broader goals of sustainable development and food security.

Study objectives

The main objective of the study was to assess the feasibility of on-site tea organic waste usage either as an alternative or supplement to chemical fertilizers for agricultural application in Mulanje district. Specifically, the study sought to:

i. Evaluate composition of plant nutrients (Nitrogen, potassium and phosphorus) in solid tea waste generated during Tea processing.
ii. Compare the plant nutrients *(N: P: K)* from solid tea waste generated during Tea processing with that of the chemical fertilizers utilized in agricultural practices.
iii. Assess the financial implications of substituting chemical fertilizer with tea waste as organic fertiliser.

1.3. Study significance

This study will be of benefit and interest not to the tea industry but to other industries such as energy sector as the waste could be the source of energy; poultry and fish farming as the organic wastes are used as feed hence increases the production. Secondly, it will contribute to the existing literature on organic tea waste recycling and provide insights to other agricultural researchers who would want to do further research in this area such as assessing the effects of organic waste usage on crop yields. Thirdly, entrepreneurs would leverage from financial benefits of producing, selling and utilization of organic fertilizers produced from tea waste. Furthermore, if properly managed as a resource, waste recovery and recycling can create new jobs and attract new investment in a diversified waste sector. In general, substituting chemical fertilizers used in agricultural crops with organic fertilizers and manure holds significant importance on global, regional, and national/local agendas. On a global scale, this shift aligns with the Sustainable Development Goals (SDGs), particularly Goal 2: Zero Hunger, and Goal 12: Responsible Consumption and Production. By adopting organic fertilizers, farmers can enhance soil health and fertility, leading to improved crop yields and food security, thereby contributing to the goal of eradicating hunger and promoting sustainable agricultural practices. Additionally, the reduction of chemical fertilizer use reduces the risk of environmental pollution, protecting water resources, and mitigating climate change, aligning with Goal 13: Climate Action and Goal 15: Life on Land.

Regionally, in the context of Africa's Agenda 2063, the substitution of chemical fertilizers with organic alternatives supports the vision of "The Africa We Want," fostering sustainable agricultural growth and food self-sufficiency. Organic fertilizers promote soil conservation, reduce degradation, and enhance ecosystem resilience, aligning with the agenda's aspiration for a prosperous and environmentally friendly Africa.

At the national and local level, in the case of Malawi's Vision 2063, adopting organic fertilizers plays a crucial role in achieving sustainable agriculture, economic growth, and environmental protection. By reducing reliance on costly and imported chemical fertilizers, farmers can enhance economic resilience and foster local entrepreneurship around compost production. Moreover, using organic fertilizers helps address environmental concerns like water pollution and soil degradation, thus safeguarding the country's natural resources for future generations and contributing to Malawi's sustainable development goals.

In conclusion, the substitution of chemical fertilizers with organic fertilizers and manure is not just a farm-level practice but a strategic step towards fulfilling global commitments, regional aspirations, and national development agendas. Embracing organic fertilizers empowers farmers to achieve food security, fosters environmental stewardship, and paves the way for a more sustainable and resilient agricultural sector, aligning with the collective vision for a better future on multiple levels.

1.4. Chapter summary and organization of the dissertation

The chapter has presented the study background on the assessment of the levels of NPK in organic tea waste and its onsite usage financial feasibility. Limited knowledge on organic tea waste economic benefits and its utilization in tea fields and other crop fields as an alternative to the current inorganic fertilizers has necessitated this study. The findings of this study will add value to existing literature and provide Entrepreneurs a niche of business opportunity to exploit. The chapter has also outlined specific research objectives for the study.

The rest of the dissertation has been organized into four more chapters: Chapters two to five. Chapter two provides a brief literature review where by the study looks at theoretical literature and empirical literature. Chapter three focuses on the methodology adopted in the study, by specifically discussing the research design, data analytical tools and techniques. Chapter four presents and discusses the study results. Chapter five provides conclusions and recommendations of the study.

CHAPTER 2: LITERATURE REVIEW

2.1. Introduction

This chapter reviews literature on the feasibility of on-site tea organic waste usage either as an alternative or supplement to chemical fertilizers for agricultural application. The chapter outlines the concept of waste management and the significance of sustainable waste management with a focus on organic tea waste recycling. The chapter also outlines the tea processing procedure as well as the types of waste generated throughout the process.

2.1.1 The Concept of Waste

Background and Historical Perspective

The production of wastes mostly from human activities remain a major source of concern as it has always been since pre historic period (Amasuomo & Baird, 2016). In recent times, the rate and quantity of waste generation have been on the increase. As the volume of wastes increases, so also does the variety of the waste increases (Amasuomo & Baird, 2016). A substantial increase in volume of wastes generation began in the sixteenth century when people began to move from rural areas to cities as a result of industrial revolution (Amasuomo & Baird, 2016). This rural-urban migration of people to cities led to population explosion that in turn led to a surge in the volume and variety in composition of wastes generated in cities. It was then that materials such as metals and glass began to appear in large quantities in municipal waste stream (Amasuomo & Baird, 2016). The large population of people in cities and communities gave rise to indiscriminate littering and open dumps. These dumps in turn formed breeding grounds for rats and other vermin, posing significant risks to public health (Amasuomo & Baird, 2016). The unhealthy waste management practices resulted in several outbreaks of epidemics with high death tolls (Amasuomo & Baird, 2016). Consequently, in the nineteenth century public officials began to dispose waste in a controlled manner in other to safe guard public health (Amasuomo & Baird, 2016).

Waste management has become a major concern for the 21st century as most human undertakings and activities generate waste (Brunner & Rechberger, 2014). Statistics indicate that globally, over 1.3 billion tons of solid waste was produced yearly by 2012 and about 2 billion tons of municipal waste alone was produced in 2016 (about 270kg per person) and the figures are expected to rise (World Bank 2012; 2019). Evidence indicate that rapid population growth, urbanization and high economic growth and consumption levels are some of the factors that have contributed to release of waste to the environment (Blanchard, 1992; Gerbens-Leenes et al., 2010; Wenheng and Shuwen, 2008).

High waste generation are also associated with several African economies. For example, it is empirical to note that the Sub-Saharan Africa alone produces approximately 62 million tons of waste per year (5% of the global production) as opposed to the OECD countries who produces about 44% of global waste (572 Million in tons) with a per capital of 2.2kg per day compared to the 0.65kg per day for those is Sub-Saharan Africa (World Bank, 2012).

Waste can be defined as the useless by product of human activities which physically contains the same substance that are available in the useful product (Amasuomo & Baird, 2016). Wastes have also been defined as any product or material which is useless to the producer (Amasuomo & Baird, 2016). Albeit waste are materials that people would want to dispose of even when payments are required for their disposal. Although, waste is an essential product of human activities, it is also a consequence of inefficient production processes whose continuous generation is a loss of vital resources (Amasuomo & Baird, 2016).

It must be mentioned at this point that what one considers can be used and converted into a resource to another.

Classification and Types of Waste

Waste arises in many different forms and its characterisation can be expressed in several forms. Some common characteristics used in the classification of waste includes the physical states, physical properties, reusable potentials, biodegradable potentials, source of production and the degree of environmental impact (Amasuomo & Baird, 2016). Amasuomo & Baird (2016) indicated that waste can be classified broadly into three main types according to their physical states; these are liquid, solid and gaseous waste. Although it is clear that several classifications exists in different countries. The most commonly used classifications are physical state (Solid waste, liquid waste, gaseous waste), Source (Household/Domestic waste, Industrial waste, Agricultural waste, Commercial waste, Demolition and construction waste, Mining waste) and Environmental impact (Hazardous waste and Non-hazardous waste) (Amasuomo & Baird, 2016).

Some Common Sources/Types of Solid Waste

Since solid waste consist of several types of waste, it is important to briefly examine the various forms and types of solid waste. These can be Municipal Solid Waste (MSW), Construction Waste, Industrial Waste, Agricultural Solid Waste, Commercial Waste (Amasuomo & Baird, 2016).

Municipal solid waste (MSW) is waste stream that people often come in contact with, their collection, treatment and disposal is considered as an important service by politicians and local government (Amasuomo & Baird, 2016). Municipal solid waste is the waste collected by the city authorities which include refuse from household, non-hazardous solids from industrial, commercial, institutional and non-pathogenic hospital waste. Sources of MSW include domestic, commercial sources (Amasuomo & Baird, 2016).

Solid waste from the construction industry is one of the main waste streams in many countries. For example, in Hong Kong, construction waste amounted to about 29,674.013 metric tonnes per day (Amasuomo & Baird, 2016). Most of the construction wastes produced in Hongkong included both inert and non-inert materials (Amasuomo & Baird, 2016). Furthermore, the huge volume of solid waste generated by the construction industry in Hong Kong is as a result of the limited availability of land in the country (Amasuomo & Baird, 2016). As a result of the boom in the construction of multi-story buildings in the city about 21.5 million tonnes of construction waste was produced in 2005 alone (Amasuomo & Baird, 2016).

Industrial waste is waste produced as a result of the processing of raw materials for the production of new products (Amasuomo & Baird, 2016). These could be from factories, mines or even mills.

Agricultural wastes are wastes arising from agricultural activities such as the rearing of livestock, sowing of plants and from milk production (Amasuomo & Baird, 2016). Agricultural waste materials include animal manure, various crop residues and silage effluent. Agricultural wastes are mostly reusable in the energy and industrial sector (Amasuomo & Baird, 2016).

Commercial waste is solid waste generated by commercial and industrial. These include waste from retailing, wholesales, hotels and restaurants. Commercial solid wastes are solid or semi-solid wastes produced as a result of activities in stores, restaurants, markets, offices, hotels, motels, print shops, service stations, auto repair shops among others (Amasuomo & Baird, 2016).

2.1.2 Waste Management

Waste management refers to the "collection, transportation, processing, recycling or disposal of waste materials" ((Tsai, 2007) as cited in (Sichiweza, 2017). Waste management practices differ for developed and developing countries, for urban and rural areas, and for residential and industrial producers. In waste management strategies, an appreciation of quantities and characteristics of the waste generated is crucial in developing robust and cost-effective management methods. However, responsible institutions little attention is given to different characteristics of waste, seasonal variations and future trends of waste generation (PDAC, 2009). There are different steps in waste management strategies such as identification of source of waste, reduction and minimization, and disposal options. Avoiding onsite waste disposal and categorization of waste accordingly enhances waste recycling process (PDAC, 2009). The process is part of sustainable waste management which deals with the optimization of scarce raw materials and minimization of use of energy.

2.1.3 Sustainable waste management

Sustainable waste management involves the control of generation, storage, collection, transportation, processing and disposal of solid waste with the aim of protecting environmental quality, human health and preservation of natural environment (Crown, 2012). Used as conservation approach, the emphasis is laid on reduction, reusing and recycling of bio-degradable and non-biodegradable waste and providing an environmentally friendly option to manage waste (Crown, 2012; Ogunrinola & Omosalewa, 2012). Furthermore, there are two options in waste management: the most favored option is preventing waste so that there is little waste to be disposed and on the other hand least favored option is allow waste to be produced and have it disposed (Crown, 2012). The first R (reduce) involves prevention and reduction of waste. To reduce waste means to minimize amounts of waste generated. Waste reduction stresses upon judicious use of resources in manufacturing. The second R (reuse) involves secondary and subsequent uses of waste materials either in part or as a whole. Reuse of waste is exemplified by trade in secondhand goods, such as clothes, electronics, automobiles, furniture and other merchandise (Sichiweza, 2017). Reuse is achieved through sorting done at the source rather than the disposal site and through detailed processes of checking, cleaning, refurbishing, repairing whole items or spare parts (Crown, 2012). The third R (recycle) depends on waste materials, which cannot be reused directly but can be converted to new products or raw materials through the processes of transformation (Crown, 2012). For instance, used paper is recycled into files, envelopes and cards. In addition, energy is recovered through recycling by pyrolysis, which is a process that involves combustion of waste in the absence of oxygen to create gases, liquids and solid compounds. The "3Rs" are aimed at achieving sustainable solid waste management and relates to other global environmental challenges. These challenges include climate change mitigation and specifically, the emission of greenhouse gases that could create sustainable development co-benefits and reduction in the emissions of methane (CH_4), biogenic carbon dioxide (CO_2), non-methane volatile organic compounds (NMVOCs), nitrous oxide (N_2O), nitrogen oxide (NOx) and carbon monoxide (CO) from landfills (Crown, 2012).

2.1.4 Utilization of biowaste for fertilizer production and plant growth

The use of chemical fertilizers containing mainly of nitrogen, phosphorus, and potassium (NPK) over the years have caused significant environmental impacts as these fertilizers have been applied widely over numerous lands across the world (Savci, 2012). This calls for the need to recycle various types of biomass waste such as animal manure, sewage sludge waste, and food waste into organic fertilizers. Organic waste for utilization as agricultural fertilizers can be classified into several categories, namely: Animal-based organic waste (manure), compost (plant sources and food waste), and urban waste (sewage sludge and household waste) (Uysal et al., 2014). These wastes are processed to optimize their nutrients content and promote their agricultural value for the contribution to a more bio-friendly economy and environment. There are many processing techniques to synthesis the organic fertilizers and the management of these biomass waste are essential to develop a sustainable cycle in terms of manageability, fertilizer value, soil amelioration value, as well as the environmental impacts (Bratina et al., 2016). Composting is a sustainable technique that converts these organic and biodegradable food waste into a stable form of organic matter and fertilizers that can be used for agriculture as soil amendments (Wolka & Melaku, 2015). The content and quality of compost is dependent on the types of raw materials used, process of composting, conditions of decomposition process, and addition of nutrients during composting. The conversion of food and municipal solid waste to compost and its utilization for improving crop productivity and soil fertility will contribute to the soil organic matter management and reduction of the carbon footprint (Razza et al., 2018). Generally, the use of organic waste as compost in agriculture has several other advantages that range from sustainable replacement to chemical fertilizers, conservation of limited and non-renewable rock phosphate utilized as chemical P fertilizer in fertilizer production, the improvement in soil nutrient profile, structure and reduced soil erosion, climate change mitigation due to reduced greenhouse gases emissions from waste decomposition in open dumps, conservation of land resource due to reduced amounts of landfilled waste, reduction in volume of wastes from dumpsites and minimize environmental pollution, among others (Sharma et al., 2019). Eden at al. (2017) noted that decreasing organic matter content in the soil results in the direct lowering of soil fertility and ultimately reduce yield with massive negative effects on soil properties. Sharma et al. (2019) noted that the usage of organic wastes provides a double opportunity of soil conditioning and sustainable organic waste management. Gurav et al. (2013) reported that compost application to agricultural land can result in changes in soil physical properties such as structure, water retention and infiltration rates, biological properties and crop yields. Organic materials such as compost can act as a valuable source of plant available nutrients (e.g. nitrogen (N), phosphorus (P), potassium (K), sulphur (S) and magnesium (Mg)) and thereby reduce the need for manufactured fertilizer inputs (Gurav et al., 2013).

Odlare et al. (2015) noted that recycling of organic wastes in agriculture remains key reducing the need for mineral fertilizer and play a pivotal role in the restoration of organic carbon deficiency in the soil. A number of problems arise from the lack of proper organic waste management. These problems include environmental pollution, eutrophication, esthetic damage to urban landscape, greenhouse gases emission and effects on human health (Odlare et al., 2015). Even though organic waste has economic value, improper disposal of wastes results in a dual problem namely threat to environmental quality and loss of economic value of organic waste (Odlare et al., 2015). . Organic wastes serve as an important source of organic matter and important plant nutrients. Agricultural recycling of organic wastes serves as an opportunity to add value while conserving the environment. Sharma et al. (2019) established that the practice of using organic wastes incorporates indirect environmental benefits such as reduced greenhouse gas emissions, land conservation due to reduced landfilling of wastes and substitute to chemical fertilizers. Form the economic angle, agricultural utilization of organic wastes reduces the cost of landfilling, transportation of wastes, imports and production cost of chemical fertilizers and opens avenues for rural employment (Sharma et al., 2019). Ibrahim et al. (2014) noted that organic fertilizers are an environmentally friendly substitute for harmful chemical fertilizer. They enrich the nutrient quality of soil and transform organic matter into nutrients that can be used to make plants healthy and productive (Ibrahim et al.,2014). They are usually help support carrier-based inoculants containing effective microorganisms (Ibrahim et al.,2014). The biodegradation of such materials to simple sugars provides energy sources for heterotrophic microorganisms such as P-solubilizing and nitrogen fixing bacteria (Ibrahim et al.,2014). They help main inoculants such as bacteria, fungi, and cyanobacteria (blue-green algae) to function. These microbes have various abilities which could be exploited for better farming practices (Ibrahim et al.,2014). Some of them help in combat diseases while some have the ability to degrade soil complex compounds into simpler forms which are utilized by plants for their growth (Ibrahim et al.,2014). They are extremely beneficial in enriching the soil by producing organic nutrients for the soil and to convert insoluble phosphates to a form accessible to the plants for increasing plant yields (Ibrahim et al., 2014). Much as using organic waste in agriculture offers various benefits, such as improving soil health and providing essential nutrients to crops, there are also significant potential dangers associated with this practice that must be carefully managed to ensure safety and environmental sustainability. Organic waste, particularly manure and food waste, can harbor harmful pathogens such as E. coli, Salmonella, and Listeria. If these pathogens are not adequately treated, they can contaminate crops, leading to serious health risks for consumers. Proper composting and treatment processes are crucial to eliminate these pathogens before applying organic waste to fields (Duffy et al., 2013). Certain organic wastes can contain heavy metals, including cadmium, lead, and mercury. These metals can accumulate in the soil over time and be absorbed by crops, potentially entering the food chain and posing health risks to humans and animals. Regular testing and monitoring of organic waste sources are necessary to prevent heavy metal contamination (Wuana & Okieimen, 2011). Some organic wastes may contain weed seeds that can germinate and compete with crops for nutrients, water, and light. This competition can reduce crop yields and increase the need for weed management practices. Ensuring that organic waste is properly composted can help kill weed seeds and minimize this risk (Fennimore et al., 2014). Decomposing organic waste emits greenhouse gases such as methane (CH4) and nitrous oxide (N2O), which contribute to climate change. Proper management and composting techniques can mitigate greenhouse gas emissions, but improper handling can exacerbate the problem (IPCC, 2007).

2.1.5 The Role of Organic and Inorganic Fertilizers in Tea Production

Islam et al. (2017) observed that tea plant needs large amount of micro and macro nutrients for its growth. The deficiency of these nutrients could adversely affect the yield and quality. These nutrients are critical and their deficiency and inadequate supply would eventually lead to poor seedlings establishment and performance. In fact, tea plant need large amount of N, P, K and Mg for its growth (Islam et al.,2017). Tea cannot be produced optimally without fertilizer application and external nutrient addition (Islam et al.,2017). Tea production is commercially being done by nutrients supply through inorganic fertilizer at rates between 150 kg-300kg N/ha for black tea (fermented tea) Islam et al. (2017). The use of inorganic fertilizer helps in production and it is somewhat quick method for achieving maximum yields in the short term. Tea yield increases sharply with increased levels of N and K to a certain point Islam et al. (2017). Tea being a leaf crop, in the flush shoot the nitrogen content is the highest followed by potassium (K), calcium (Ca), phosphorus (P), sulfur (S), magnesium (Mg) and zinc (Zn). Nitrogen (N) is an important constituent of plants parts and plays a vital role in the physiology of the tea plant. It is estimated that harvestable crop contains 3.5-5% N on dry matter basis. Although applications of N can increase tea yields, the quality of the manufactured product is suppressed by large N rates. Potassium and magnesium are required in large quantities and they are both involved in almost all biological reactions. Potassium is the second major nutrient for tea after N and makes up 1.5-2% of the dry matter in tea leaves. Response of potassium occur only whenever pH is lower than 5.2. The quality of made tea depends on organic and inorganic composition of harvested shoots, which are changed into the substances, these are responsible for taste, flavor and color of made tea. In this regard, balanced nutrition of tea is of particular importance to secure good harvested fresh leaves as a prerequisite for tea of superior quality. Islam et al. (2017) argued that agro- chemicals are unable to sustain production increases and cannot restore soil fertility, solutions must be found to recover the soil's original characteristics (as in the forest), i.e., its biological, physical and chemical properties, before it becomes degraded (Islam et al., 2017). Heavy application of inorganic fertilizers leads to deterioration of soil cation exchange capacity (CEC) and clay contents of the soil, high concentration of Al and silicate in drainage water in addition to air pollution through nitrous gas emission, excessive leaching leads to underground water pollution (Islam et al., 2017). Also due to high cost of inorganic fertilizers and the poor resources, farmers cannot afford such types of fertilizer so this is need to look for alternative resource, that are cheap, readily available and affordable i.e FYM, compost, EM etc (Islam et al., 2017). The inorganic fertilizers are usually not available and are always rather expensive for the low- income, small-scale farmers. Application of organic fertilizers is one of important practical measures to improve soil fertility. In addition to providing necessary nutrients for crops and improving soil physico-chemical properties, organic fertilizer is able to enhance soil microbial activity of soil, such as improving activity of soil enzymes and increasing soil microbial biomass. Organic fertilizers have traditionally been used in agricultural areas, especially in view of their benefits for the soil biological and chemical properties (Islam et al., 2017). It is worth remembering that the addition of organic residues is fundamental for carbon (C) recycling in the soil and can improve its physical quality. Organic manures can be used as an alternative for the inorganic fertilizers. They release nutrients rather slowly and steadily over a longer period and also improve the soil fertility status by activating the soil microbial biomass. The objective of organic tea cultivation is to have an eco-friendly plantation aimed at the conservation of ecology and natural habitat without polluting soil, air and water and yet maintaining sustainable tea production (Islam et al., 2017). Here, tea is producing the absence of synthesized chemicals like pesticides, fungicides, herbicides, growth regulators and concentrated fertilizers. Naturally occurring mined products and bulky concentrated organic manures are used for nutrition and maintenance of soil fertility. (Islam et al., 2017). During the transition from chemical based agriculture to organic farming, decline in productivity has been noticed (Islam et al., 2017). However, it has been reported that establishment of organic tea right from planting gave more desirable results in terms of productivity and net return (Islam et al., 2017).

Islam et al. (2017) concluded from their study that organic fertilizer performed the best and lowered the soil pH which is required for the growth of tea. Plant height, number of leaves and number of branches, organic matter were enhanced due to application of maximum dose of organic fertilizer. Since the chemical fertilizers deteriorate the physical properties of soil and organic fertilizer improve physical properties and fertility status of the soil, improves water holding capacity and structure of the sandy soil, the chemical fertilizer may be replaced with organic fertilizer.

2.1.6 Productivity and Profitability of Using Inorganic Fertilizers versus Organic Manures

The study is spearheading the argument that the use of inorganic fertilizer generated from tea waste not only increase productivity on yield basis but also profitability in the long term. Notwithstanding being pricy, the use of inorganic fertilizer seems profitable and yielding in the short term, the effects of the use of inorganic fertilizer on soil health are devastating (Kumar & Kumawat, 2014; Xu et al.,2009). Kumar & Kumawat (2014) noted that, “since use of chemical fertilizers is the quickest and surest way of boosting the crop production to achieve the food security but their escalating costs, diminishing resources, deterioration of soil health and environmental degradation has necessitated use of potential alternative sources of plant nutrients”. Thus, use of organic sources of plant nutrient not only makes economic sense but is also instrumental in sustaining the soil productivity and soil health but also in meeting out a part of chemical fertilizer requirement of intensive cropping system (Kumar & Kumawat, 2014; Manther et al., 2016).

A study by Neem et al. (2006) conducted a field experiment to determine the effect of organic manures and inorganic fertilizers on growth and yield of mungbean (*Vigna radiata* L.). The experiment comprised of two varieties (NM-98 & M-1) and four fertility levels as NPK @ 25 - 50 - 50 kg ha , poultry manure @ 3.5 t ha , FYM @ 5 t ha and Bio-fertilizer @ 8 g kg seed. NPK fertilizers and organic manures were applied at the time of seed bed preparation (Neem et al., 2006). The findings of the study indicated that wheat grain yield was recorded highest (1104 kg ha^{-1}) with the application of the inorganic fertilizers (NPK @ 25 - 50 - 50 kg ha^{-1}) (Neem et al., 2006). Among organic nutrient a source, poultry manure @ 3.5 t was found the best followed by FYM @ 5 t ha (Neem et al., 2006). However, both varieties were equal in grain yield. Numbers of pods, number of ha seeds per pod, 1000 grain weight were also almost higher in inorganic fertilizer treatment (Neem et al., 2006). The important aspect that ties with this study on profitability. The economic analysis revealed maximum net benefit from the treatment, where organic manure was applied (Neem et al., 2006).

Ngwira et al. (2013) noted that the declining soil fertility is a major constraint limiting African agriculture. This declining soil fertility is caused by the continuous cropping and insufficient organic matter return to the soil that poses a threat to crop productivity in most smallholder farms of sub-Saharan Africa in general and Malawi, in Particular (Ngwira et al., 2013). Ngwira et al. (2013) conducted a four-year (2007–2011) on-farm study in Malawi there they compared the effects of compost (bokash and liquid manure) and compost (bokash) in combination with low doses of inorganic fertilizer with recommended inorganic fertilizer rates on the performance of three maize genotypes. The results showed that compost use resulted in increases in soil organic carbon, total nitrogen, available phosphorus, and soil pH (Ngwira et al., 2013).

2.1.7 Circular economy

First introduced in the 1970's and re-introduced in 2012 by Ellen MacArthur Foundation, circular economy Model (CEM) as defined by Kirchherr et.al, 2017, is combination of reduction, reuse and recycle activities in management of waste. Additionally, Kobza and Schuster (2016), define circular economy as pertaining to life-cycle planning that aims at preserving materials or products in the value chain for as long as possible where a product turns into a raw material at the end of its life phase. Circular economy concept aims to close the loops, provide employment and minimize the impact on the environment and health of people and it is becoming increasingly important on the agendas of policy makers (Blomsma & Brennan, 2017). Three principles exist to define this model and; thus, design out waste with a goal for waste not to exist; keeping components and materials at their highest value in use, and regenerating natural systems by using renewable materials for plastic production.

This concept is also about an "industrial economy" that promotes greater resource productivity to reduce waste to avoid pollution by design or intention, in which material flows (Ellen MacArthur Foundation, 2015). Waste traditionally has been viewed as having no value. In a resource-efficient economy and society, the term "waste" would refer only to those residual materials that have absolutely no potential to be utilized and, therefore, no economic value.

Under this definition, traditionally "valueless" streams of waste can be considered resources for a new tier of the economy. They can be recovered (or prevented from being lost) through greater efficiency and management at every stage of production and consumption. Even some hazardous or toxic materials may be recycled or re-refined for reuse (Ellen MacArthur Foundation, 2015). In one way or linear economy little effort is made to reduce the amount of materials consumed in production which leads to waste production (Mohanty, 2011). Further, little effort is made to reuse or recycle the waste which mainly go for landfill as it can be seen in Figure 1.

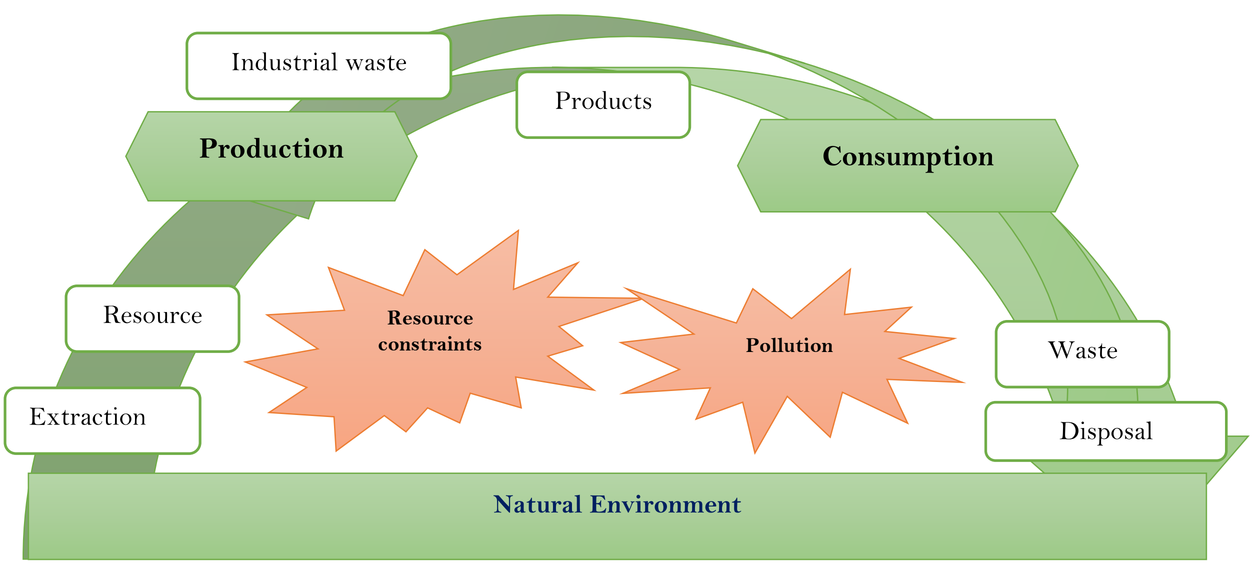


Figure 1: Unsustainable Pattern of Economy. Source ADB (2002)

In a circular economy, nearly all outputs either become inputs to other manufacturing processes or are returned to natural systems as benign emissions rather than as pollutants as described in Figure 2.

Figure 2: Sustainable Resource-Efficient Economy with 3Rs. Source: ADB (2002)

Globally, the circular economy policy platforms have increased more over the previous two decades (Preston et al., 2019). However, circular economy trend of thought has been there from the 1970s, albeit specific policies referring to the circular economy began to get introduced mostly in the 2000s (Preston et al., 2019). Two groups were in the fore front of spearheading the circular economy agenda at the global level and these were the European Union (EU) and China (Preston et al., 2019). For example, in 2009 the Chinese introduced its own Circular Economy Promotion Law that has advanced into a series of supporting policies, including the State Council's Circular Economy Development Strategy and Near-Term Action Plan, issued in 2013; and the Promotion Plan of Extended Producer Responsibility, introduced in 2016 (Preston et al., 2019). While in Europe, high-level discussions on this topic began in 2011 amidst concerns about high commodity prices. This followed the announcement of the Action Plan for the Circular Economy by the EU in 2015. Ever since the introduction of the EU Action Plan, the EU has developed and announced a number of policy announcements specially dedicated to circular economy strategies for EU member states and cities (Preston et al., 2019).

From the private sector perspective, the talk on sustainability has proven that companies become profitable in the long-term and this has instilled a level of engagement by private companies such as Google, Unilever and Renault in exploring circular approaches (Preston et al., 2019). These companies see and envisage the potential for cost savings emanating from the adoption of more resource-efficient supply chains (Preston et al., 2019). This has also brought some level of creativity and innovation among some companies that see the potential in the circular economy. For example, a multinational electronics company called Ricoh started collecting, disassembling and reusing the component parts of printers, scanners and other office equipment (Preston et al., 2019).

Desmond and Asamba (2019) noted that the concept of circular economy still remains vague in Africa especially in terms of an enabling legal and regulatory framework. This is attributed to the fact that the legal and regulatory frameworks required to facilitate circularity are in the state of infancy in a lot of African countries and this is further exacerbated by the fact that mechanisms to realise the transition towards green economies are often not there (Desmond & Asamba, 2019). The other problem has been that there is too much focus on China this has stolen the focus on circular economy discussions for Africa (Preston et al., 2019). Preston et al. (2019) noted that a lot of studies and analyses on circular economy have been directed more on the EU and China despite the fact that these have already the most advanced legislative policy in place on circular economy (Preston et al., 2019). This is evidenced by the fact that out of the top cited papers on this topic, 42 per cent focus on China, one focuses on Europe, with less than 5 percent focusing on developing countries (Preston et al., 2019). Notwithstanding this, some African countries are developing and actively pursuing national circular economy policies. For example, in 2017 Nigeria, Rwanda and South Africa launched the African Circular Economy Alliance (Preston et al., 2019).

As mentioned in the previous section, a circular economy is based on the concept of "3R" particularly in the context of changing consumption and production patterns. It calls for an increase in the ratio of recyclable materials, further reusing of raw materials and manufacturing wastes, and overall reduction in resources and energy used (Ellen MacArthur Foundation, 2015). These ideas are applied to the entire lifecycles of products and services from design and extraction of raw materials to transport, manufacture, use, dismantling or reuse and disposal (Mohanty, 2011).

A circular economy saves money, conserves resources, and satisfies the human urge to be creative. "A circular economy has benefits that are operational as well as strategic, on both a micro and macroeconomic level. The (Ellen MacArthur Foundation, 2015) refers to it as a trillion dollar opportunity, with huge potential for innovation, job creation and economic growth. In fact, separation of waste at the source is of paramount importance in the 3Rs initiative. However, it has been observed that recyclables with economic value such as wastepaper, plastic, broken glass, and metal etc., is not segregated and is thrown on the streets by people along with domestic or trade or institutional waste. By throwing such recyclable materials on the streets or into a common dustbin the quality of recyclable materials deteriorates as it gets soiled by wet waste which is often contains even contaminated and hazardous waste (Ellen MacArthur Foundation, 2015).

Without waste separation, the composition of wastes will not be known and planning, designing and implementation of waste management systems is not possible. Waste separation therefore is a key activity in any successful 3R initiative. According to the Department of Environmental Affairs and Tourism, wastes can be separated at three levels; household and community level, in the process of collection and transportation by municipal workers, and at the waste disposal site by the workers and waste pickers from informal sector (Mohanty, 2011). It is also important to note that in absence of recycling industries or buyers for the segregated wastes, the sorted wastes end up discarded and mixed with unsorted wastes in open spaces or at disposal sites. According to MacArthur (2014), the successful promotion and implementation of the 3R strategy require that all stakeholders become fully involved from development stage of the strategy through its implementation. This implies that solid waste management requires full participation of all stakeholders as well as coordinated effort. Therefore, solid waste management like in tea factories and estates, need to give priority to the implementation of the 3Rs so as to achieve effective results in managing waste as they process Tea.

2.1.8 Tea Waste

Tea wastes is normally referred to as waste from tea factories (Chowdhury et al, 2017). Tea waste may include discarded tea leaves, buds and tender stems of tea plants (Chowdhury et al, 2017). Tea is a popular beverage across the world. However, tea production and processing result in the production of waste. For example, in the rigorous processing of tea, fine tea demands layer upon layer selection that results in waste coming from a large number of accessories, such as tea stems, old tea and tea tree pruning branches, etc. (Gao et al., 2017). China, for example, about 20% of total gross weight accounts for annual selection of tea waste was accounting for 20% of the total gross weight of tea (Gao, 2016). The common practice for these wastes is to burn or bury them (Gao et al., 2017).

In Japan, second-picking and third- picking tea led to processing of low-grade tea. They used mechanical picking methods that led to more tea waste especially tea stems (Gao et al., 2017). Observation shown that 25% of the tea residue discharged from the tea beverage plant was tea waste. For example, Ito Park, the famous tea beverage producer in Japan, had produced 51 tons of tea waste from processing tea beverage in the only 2012 (Gao et al., 2017). And 65% of them were buried for compost, 17% for heat recovery treatment, and the rest were used as a feed or as a material additive (Gao et al., 2017). Gao et al. (2020) found that the compostability of tea residue has been proven and has been used to produce tea residue organic fertilizer that promotes plant growth. Suffice to say that there are few studies that have been conducted on the degradability of wastes such as tea stem or composites made from tea waste (Gao et al., 2020). Gao et al. (2020) argues that in order to establish a reliable and environmentally friendly tea waste recycling system, tea waste should have good degradation properties in addition to being processable. In this regard, there is need for further experiments to be conducted to prove the degradation performance of tea waste. Chowdhury et al. (2017) noted that most of tea factories of utilize their tea waste in the plantation area. They do this by using mixing the factory tea waste with 5% urea and cow dung for at least 45 days and keeping it in the soil where it gets converted into a good bio-nutrient and bio-fertilizer caffeine, this way tea waste increases the acidity of soil (Chowdhury et al., 2017). Chowdhury et al. (2017) also reported that tea waste contains significant amounts of n-triacontanol, a compound that has tea plant growth promoting properties and might also regulate different other physiological properties like the formation of leaf primordial and development of primary leaves. Most documented studies have placed emphasis on the use of waste tea leaves or tea factory wastes or factory-rejected tea as an adsorbent for the removal of effluents from water (Hussain et. al., 2018).

Mateescu (2018) noted that as with all vegetal wastes, tea waste have a high fertility value for soil and plants due to their rich content in complex organic molecules such as cellulose, hemicelluloses, proteins, lipids, poliphenols as well as many minerals. Such waste can be aerobically and anaerobically decomposed by microorganisms (bacteria, fungi and yeast) to simple molecules and oligoelements which are required for plants growth. However, Mateescu (2018) was quick to point out that a correct management practice must be considered since the uncontrolled decomposition of such waste, when directly applied on soil, may lead to environmental pollution (acid leachate that contaminates soils and groundwater, methane that is a greenhouse gas contributing to air pollution etc.). Therefore, a non-polluting practice of using tea waste as a fertilizer in agriculture is their stabilization by techniques such as composting, solid-state fermentation, thus resulting in a non-acid and non-polluting fertilizer, while the generated fuel gas (methane) can be recovered and valorised (Mateescu, 2018).

Joshi (2018) reported that making tea compost require that decomposition of tea waste is well managed in a healthy way when applied directly on agriculture land to ensure a better outcome. For example, in the context of Indian climate zone, without any stabilization techniques, and managing on site stabilization in correct way, the result is better (Joshi, 2018). In this regard, Joshi (2018) recommends the use of solid-state fermentation technique for stabilization. Therefore, solid state fermentation (SSF) is presented as a promising technology for waste valorization through the bioconversion of organic wastes used as either substrate or inert support, whilst microorganisms will play a role in the degradation of organic wastes into its constituents to convert them into high value-added products (Yazid et al., 2017). SSF shows sustainable characteristics in the bioconversion of solid wastes that have been proved to be able to give high efficiency in terms of product yields and productivities, low energy consumption, and solving disposal problems (Yazid et al., 2017). SSF is a process carried out with microorganisms growing on solid and moist substrates that act as nutrient sources and support the microbial growth in the absence or near absence of water (Yazid et al., 2017). SSF is not an entire new technology in bioprocessing since it has been mainly applied in the Asian region from ancient time, but recently it is gaining a lot of traction due to the increasing use of different types of organic wastes and the larger production of added-value products including tea waste (Yazid et al., 2017). The search for sustainable and green processes to transform traditional chemical processes also highlights the potential of SSF (Yazid et al., 2017). Outlook Krishi (2021), an agricultural policy institute in India reported that waste tea leaves can be a great source of organic material for gardens and compost piles. Tea leaves contain the three big nutrients termed NPK, i.e. nitrogen, phosphorus, and potassium. Used tea leaves not only increase agricultural yields and offer farmers an economical natural fertilizer but can reduce the heavy metal toxicity. Badar et al. (2018) noted that organic wastes as organic fertilizers positively affect soil structure and nutrient availability and can be less expensive than synthetic fertilizers. The consumption of organic wastes can increase fertility without deleterious effects on environment. It is therefore most essential to decrease the dependence on chemical inputs in agriculture. A study by Badar et al. (2018) found that tea waste improved maximum fresh weight of experimental plants. Tea waste and bottom ash as organic fertilizers boosted significantly dry weights of plants (Badar et al., 2018).

A study by Oirere (2015) found that the majority of waste generated by tea factories in Kenya was organic waste at 95.6% of the total waste produced. The waste was generated mostly from the withering stages as spillage from the overloaded troughs coupled with poor handling of green leaf during loading. The study found that 13.7% (67.0 kgs per month), 49.7% (242.3 kgs per month), 15.9% (77.4 kgs per month), 11.7% (57.0 kgs per month), 4.5% (22.1 kgs per month), and 2.7% (8.5 kgs per month) of the total wastes were generated from the leaf reception (as green leaf), withering (as green leaf), maceration (as green leaf), drying (pekoe dust), sorting (fannings) and packing (paper), respectively (Oirere, 2015). All of these wastes were organic and majority were generated as green leaf wastes.

2.1.9 Tea processing and waste generation

Tea is an evergreen plant of the Camellia genus. Its scientific name is *"Camellia Sinensis''* and it originated in China, Tibet and Northern India. According to (Oirere, 2015) the tea plant has thick leaves, dark green in color, and a strong thick stem. The tea flowers bloom in white or pink and have a delicate fragrance. Tea is highly climate-sensitive, and climate change could affect future tea production and quality. Since tea stakeholders have long planning horizons, it is important to analyze climate change impacts and potential adaptation options at a scale of existing tea plantations and with respect to the aspects of the climate to which tea production and quality is most sensitive. There are about 200 different species of the tea plant around the world. Tea is one of the most important non-alcoholic beverage drinks worldwide and has been gaining further popularity as an important 'health drink' in view of its purported medicinal value. It is served as morning drink for nearly two thirds of the world population daily. Internationally, five tea producing countries account for over 77% of the total crop produced. Malawi was one of the first countries starting to plant the tea bush in the late 1800s and is currently the third largest tea producer of the African continent-after Kenya and Uganda (CIAT, 2017). It produces approximately 10% of African tea and in 2005 and 2006 she exported 44,613,528 kilograms valued at US$ 42,213,259 (MK5, 909,856,224) and 43,979,917 kilograms valued at $48,123,417 (Mk 6,737,278,325) respectively.

According to fair trade (2010), large commercial estates account for 93% of production, with the remainder grown by some 6,500-8000 smallholders who share only 15% of the land under tea and cultivate on small plots average of less than half hectare per farmer. Most of the estates are owned by foreign companies and are based in the districts of Mulanje and Thyolo the principle tea growing regions in the South (East) of Malawi. Ownership of these commercial estates is concentrated among 11 companies, of which the largest is Eastern Produce Malawi (EPM), which owns 21 of the 44 estates. The company is a subsidiary of British Public Limited Company CAMILIA. Interestingly, all the tea estates are Members of Tea Association of Malawi Limited (TAML) an organization that control and dictate some policies to the members. Tea in Malawi is mostly produced in the districts of Mulanje and Thyolo in the Southern regions of the country as well as in Nkhata-Bay in the Northern Malawi with Mulanje and Thyolo districts being the districts with the highest tea production in Malawi (CIAT, 2017). Tea production in Malawi has been on the rise over the years as can be seen from Figure 3. This may imply even the generation of tea waste has been on the rise as production and processing of tea generates waste. Roughly one-third of Malawi’s crop is sold through the Limbe Auction the rest is sold directly to exporters. Major international companies such as Unilever and Tata Tetley buy a high proportion of the tea. The biggest export destinations are the UK and South Africa. The color and brightness of Malawi tea is a key factor in blending of leading British tea brands (Malawi tea, 2002).

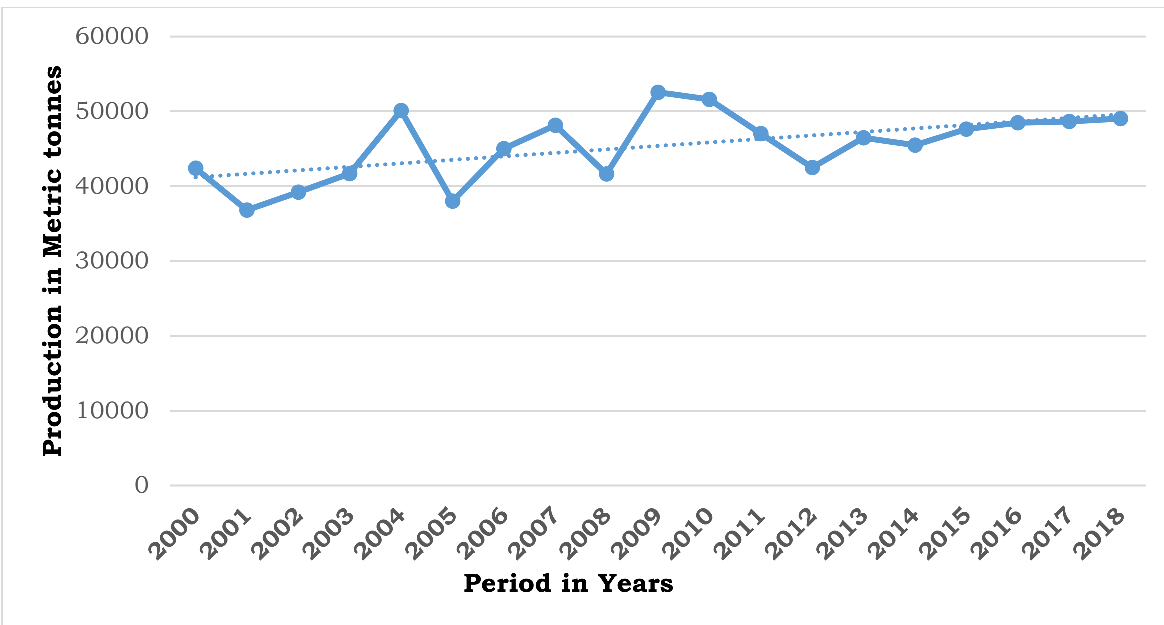


Figure 3: Tea Production Trends in Malawi. Source: FAOSAT (2020)

According to (TBK, 2008) the tea processing stages include: leaf collection, withering, rolling/maceration, fermentation, drying, sorting/grading. This section will discuss them in detail.

2.1.9.1 Leaf collection

The manufacturing process starts the moment tea leaves are plucked. The plucked leaves start to wither and at this point improper handling and transport would result in bruising of the leaf and initiation of uncontrolled fermentation leading to reduced quality. Furthermore, according (TBK, 2008) care should be taken when transporting green leaf to avoid heat accumulation and bruising. The use of suspended gunny sacks (about 10kg of green leaf) usually allows enough ventilation to avoid heat accumulation during transport from the field to the factory, provided the leaf does not overstay in the field or in the transport vessel (TBK, 2008).

Transportation to the factory can be in any other convenient containers if tea is transported within an hour. The standard of plucking also affects the quality of made tea. A finer plucking that is two leaves and a bud standard would produce a higher quality tea that will fetch a better price (TBK, 2008). It is important to have a constant supply of leaf with consistent plucking standard so that the factory does not have to change the manufacturing conditions (TBK, 2008).

2.1.9.2 Withering

The first stage of black tea manufacturing is withering. This refers to the changes (physical and chemical*)* that occur in green tea leaf from the time it is detached from the plant to the time of maceration (TBK, 2008). Physical withering is moisture loss of fresh tea leaf (and related physical changes), while chemical withering involves biochemical changes, which solely depend on time (TBK, 2008). This aspect of tea manufacture is very expensive in terms of space, time, energy and Labour utilisation. This process forms the basis of black tea processing. Withering occurs after the freshly plucked shoots are placed in the withering trough and air is blown through them for 14 to 18 hours. During this process, the most noticeable change is moisture loss which is accompanied by cell wall permeability changes which make subsequent maceration easy. This process of moisture loss and cell wall permeability changes is called physical wither (TBK, 2008).

However, less obvious is the chemical wither. This starts immediately the leaf is detached from the bush and chemical reactions involved in senescence start (TBK, 2008).

The chemical wither reactions include changes in the activity and nature of polyphenol oxidase *(*the enzyme responsible for turning green tea leaf to brown-black) hydrolysis of terpenoid glycosides to release terpenes, breakdown of proteins to amino acids, hydrolysis of lipids to free fatty acids, the breakdown of carotenes to simple terpenes. Although these changes may affect black tea aroma, they also affect plain black tea quality parameters (TBK, 2008). Chemical withering is mandatory for production of high-quality black teas. However, it is very difficult to control chemical wither duration in a commercial factory processing situation. Optimal chemical wither varies from 6 to 20 hours. Shorter chemical wither times produce green and harsh black teas, while longer withering durations result in dull black teas with low sensory evaluation (TBK, 2008).

Physical wither enhances factory throughput. The softly withered leaf is bulky and this slows down roto vane output, and driers may not cope with excess moisture in the leaf. Consequently, withered leaf should have up to 72% moisture content if the driers are to give optimum throughput.

During the period of increased tea production, many factories usually face constraints in processing especially in the withering section. Studies have shown that the two staged withering technique where chemical and physical withers are done at distinct stages make black teas with similar quality as black teas made through conventional one stage withering technique where physical and chemical withers are done concurrently. However, in a two-staged wither chemical wither must be done before physical wither and during the process black tea quality can be enhanced by using cold air to achieve physical wither. This knowledge has led to the development of tanks which occupy less space but hold more leaf and use less electricity as suitable vessels for chemical wither. Where tanks are not installed, factories can alternate overloaded withering troughs with normal loads.

Upon achieving a chemical wither, the normal loaded troughs can be subjected to forced physical wither high speed air current. After physical wither has been achieved the leaf is removed for maceration while the leaf in the loaded troughs is sub divided into those emptied troughs then subjected to forced physical wither. This process allows the factory to hold up to 35% more leaf in the factory than it could under traditional trough withering system.

The constraint in withering space is more acute during peak crop seasons when the black tea produced are generally plain. Such teas can be manufactured without quality loss if chemical withering time is reduced to as short as six hours. The reduction of chemical withering time would permit factories to start processing early and thus create extra processing time. Additionally, the same enables the factory to use withering trough more than once a day, thus enabling the factory to hold more leaf.

Since the leaf produced during peak crop period produces plain black tea and because for such teas softer withers makes superior teas, factories which can cope with softer withers without suffering reduction in throughput at the rotor vanes or dryers as a result of some engineering modifications can use tank wither only. In such manufacturing processes, all moisture is removed during drying. Due to increased surface areas macerated leaf, energy may be more efficiently utilized as moisture losses through evaporation are achieved faster. Economic survey has shown that it is more effective to install some withering tanks in factories than to build new factories or expand old factories with traditional withering technique (TRFK, 2002)

It is imperative to note that the amount of waste associated with this process is minimal as a result of broken hessian nets or holes on the troughs.

Figure 4: Withering Process.

2.1.9.3 Rolling

Almost all tea produced in developing countries is processed by unorthodox maceration/Rolling, usually using one rotorvane and three Crush, Tear and Curl (CTC) machines in series or on rotorvane and a Lawrie Tea Processor (LTP). TBK, (2008) argues that this is suitable because the tea produced are mostly plain teas, and it is not necessary to preserve all delicate flavour components.

Teas made by unorthodox maceration are generally much smaller in particle size than those made by traditional (orthodox) maceration, and they give brighter, brisker and more coloured infusions (TBK, 2008). This is also of advantage to the tea market which has moved towards tea bags and “quick brew teas” over the last twenty years.

Furthermore, the object of the maceration step is to mix up the catechins and the enzymes in the tea leaf tissues, and to allow free access of oxygen. This allows fermentation to proceed, producing theaflavins and thearubigins respectively. In delicately flavoured teas, other chemical reactions may be of equal importance (TBK, 2008). The first step in maceration is usually the use of a rotorvane. It consists of a cylinder containing a rotating central shaft. Spiral vanes on the shaft propel the leaf along the cylinder, and distortion and twisting of the tea leaf tissues occur by rubbing and shearing action of the leaf against projections coming out of the cylinder casing. This whole process is designed to disrupt the cellular structure of the leaf (TBK, 2008).

After rotorvane maceration, leaf usually passes through a series of CTC machines which consist of two rollers rotating at different speeds in opposite directions. The surface of the rollers is serrated and their rotation in different directions produces more leaf cellular disruption by crushing and stretching and cutting it into small particles (TBK, 2008). the LTP is an alternative to CTC and maybe used in conjunction with a rotorvane. It is based on the principle of a hammer mill, with the rotating hammers disintegrating the leaf very quickly. In some factories this is considered sufficient for fermentation, but in others an extra cut with a CTC, usually in the middle of fermentation is thought to be an advantage (TBK, 2008). The next result of these maceration processes is to produce small particles of leaf and stalk that have had their internal structure broken down to allow air to easily reach the internal structure of the leaf, leading to even fermentation. The macerated leaf is known as dhool. According to TBK (2008) the waste generated from the process is mainly rejects dust and stalks/fibres.

Figure 5: Crush, Tea and Curl Machines.

2.1.9.4 Fermentation

This is the stage of manufacturing where the major chemical changes occur. In essence, fermentation requires allowing oxygen to permeate the macerated leaf so that the endogenous catechins can be converted through enzyme-catalysed reactions to theaflavins and thearubigins. Some of the aroma compounds are also formed during fermentation (TBK, 2008). Originally, the procedure was for leaf to be felt in thin layers on slabs, so that air would penetrate naturally. However, oxygen requirement of leaf macerated by unorthodox means is much higher than that processed by orthodox means. This led to the use of air forced through the fermenting dhool to increase the oxygen level available for fermentation. The air also helps cool the dhool, as the chemical reactions of fermentation generate heat (TBK, 2008).

The most fermentation system utilizes George Williamson trolleys. These have perforated metal base with a plenum chamber underneath. After loading with dhool the fermentation trolley is then attached to a duct with humidified air forced through its plenum chambers and hence through dhool, thus aerating the fermenting leaf (TBK, 2008). Because the air is humidified, the fermenting dhool does not dry out. It is possible that humidification could be dispensed with at the later stages of fermentation, causing a slight loss of moisture from the dhool, and reducing the load on the dryer. At these later stages there are less chemical reactions generating heat and oxygen demand is lower.

The second effect of humidification is that of temperature control. Use of the correct temperatures for fermentation is very important. The reason for this lies in the nature of the biochemical reactions producing theaflavins and thearubigins (TBK, 2008).

Increasing the temperature does not produce the same result in a shorter time. Higher temperatures favour the production of thearubigins, thus producing a strong, coloured tea that can easily turn out flat and muddy. Lower fermentation temperatures on the other hand favour the production of theaflavins, higher flavour index and brighter coloured teas. Thus, temperature control can change the type of tea produced. It is envisaged that, in the future when these reactions are better understood, it may be possible to change the temperature regime of fermentation to produce exactly the sort of tea that is required by the market.

The fermentation of dhool in deep fermenting beds can easily lead to the formation of “balls” of dhool, which in turn lead to uneven fermentation. This has resulted in many factories using a mid-fermentation ball break, although doubt has been expressed at its usefulness. While there is often no detectable difference between teas that have or have not received such a ball break, it is still a useful precaution for those times when processing conditions are not ideal (TBK, 2008).

Furthermore, according to (Oirere, 2015) the more recent development is the use of continuous fermentation machines. There are a host of different designs, but at the moment there are three basic types:

i. *The moving belt fermenter:* Dhool is fed onto the first of a series (usually 3 or 4) of variable speed moving belts, usually with humidified air blowing through. Transfer from one belt or from one part of the belt to the next can be accompanied by ball –breaking, and fermentation time controlled by the speed of the belt.
ii. *Trough fermenter (Linsay fermenter):*-The dhool is fed into a trough and moved along by longitudinal or transverse rotating screws or vanes. The turning of the dhool allows aeration and also prevents ball formation.
iii. *Fixed bed fermenters:* - The dhool is fed into a trough a perforated base plate through which air is blown. The dhool is then mechanically dragged along the length of the trough.

It is imperative to note that the waste produced from this process is fermented liquor (TBK, 2008).

Figure 6: Fermentation Bed.

Drying

This is the process that stops fermentation and produces a stable product of low moisture content that can be shipped and endures storage (TBK, 2008). Changes do occur in black tea after drying, but they are small and have negligible effect on tea quality if drying is done well. The process of drying tea consists of exposing the tea to a flow of hot air. Traditionally in a conventional dryer the system is designed such that the driest tea is exposed to the air first and the wettest tea (straight from fermentation) last (TBK, 2008). This is usually achieved by having the tea pass on a belt through the same stream of air 4 to 6 times, with the wettest tea farthest from the air inlet. This allows the maximum utilization of the air, but recycling is not possible because of moisture pickup (TBK, 2008).

A recent development in drying technology is the advent of the fluid bed dryers. In this form of drying the tea enters a horizontal tunnel, the base of which is perforated plate. Hot air is blown vertically through the plate and the dhool forms a fluid bed, it is suspended in a fluidizing hot air. This not only gives rapid, even drying, but a combination of air pressure and decline in leaf density forces the drying tea along the tunnel, thus removing the need for a moving tray. There are various advantages of this system; moving parts are few leading to easier maintenance. The exhaust air from the end of the tunnel can be recycled at the beginning of the tunnel, thus saving on fuel. Considerable fibre can be extracted during drying during cyclone. Finally, the tea produced has a greater bulk density; therefore, more mass can be packed in a standard container. As shipping cost depend on volume, not weight, shipping costs are reduced.

The source of fuel for dryers is a problem. Due to recent increases in the prices for oil, wood is favored by the estate sectors. This is much more difficult to achieve in small holder sector have problems obtaining sufficient wood fuel. Consequently, oil fired boilers are mostly used, resulting in increased production costs. Based on current estimates, about 10% of the production cost of tea is the cost of wood fuel. If this is replaced by oil, this figure can rise to 35%. The latter also result in a loss of valuable foreign exchange. It is possible that in the future, a considerable proportion of energy required in a tea production could be supplier by solar energy collector built into the factories. This would release land currently used for fuel wood for productive purposes, and reduce the expenditure on oil imports.

The possible waste produced at this stage is heat losses.

Figure 7: The Drying Process.

2.1.9.5 Sorting and shipping

After drying the fibre is removed from the tea before it is graded by size. The dried tea is then conveyed to the electrostatic fibre extraction rollers to clean the Tea by removing fibre thus enhancing the value and imparting quality to the tea. This process is known as sorting (TBK, 2008). The main grades, which are also called primary grades and comprise of 85-95% of the tea are fibre free, are sold at much higher prices than other grades. the grade distribution as ratio of primary to secondary grades, which affects the total income of the factory is heavily influenced by the original plucking standard, with coarser plucking leading to more secondary grades. The size distribution can also be manipulated by adjustments of CTC settings so that the factory maximizes on the grades it sells best (TBK, 2008). During this stage the waste produced is rejects dust and fibres/stalks. Most tea is transported from the producing country to the consuming country which maybe far. The packaging must be designed to maintain the quality of the tea during transportation of more than three months. The two major factors to be considered in designing the packaging material are the prevention of moisture uptake (to avoid mould growth) and the prevention of taints.

Traditionally, this has been achieved by the use of wooden tea chest lined with aluminum foil. There are however, moves in various parts of the world to replace these chests. The chest are expensive and non-reusable wooden containers which consume large amounts of wood in their production which poses a major challenge environmentally and economically. The placement of tea chest is polyethylene or aluminum foil lined multi wall paper sack. The sack is an effective barrier to moisture and taint and can be transported in containers. The sack also cost less than half the price of the tea chest. It is also possible that sacks can be used with slip-sheets thus allowing more tea to be shipped per container. The use of this system could result in a considerable saving in packaging costs especially if tea is containerized at the factory.

Figure 8: Sorting.

Tea waste from withering to grading of tea include: green leaves, moisture, dust, stalks, fermented liquor, emissions and waste water as outlined in Figure 8.

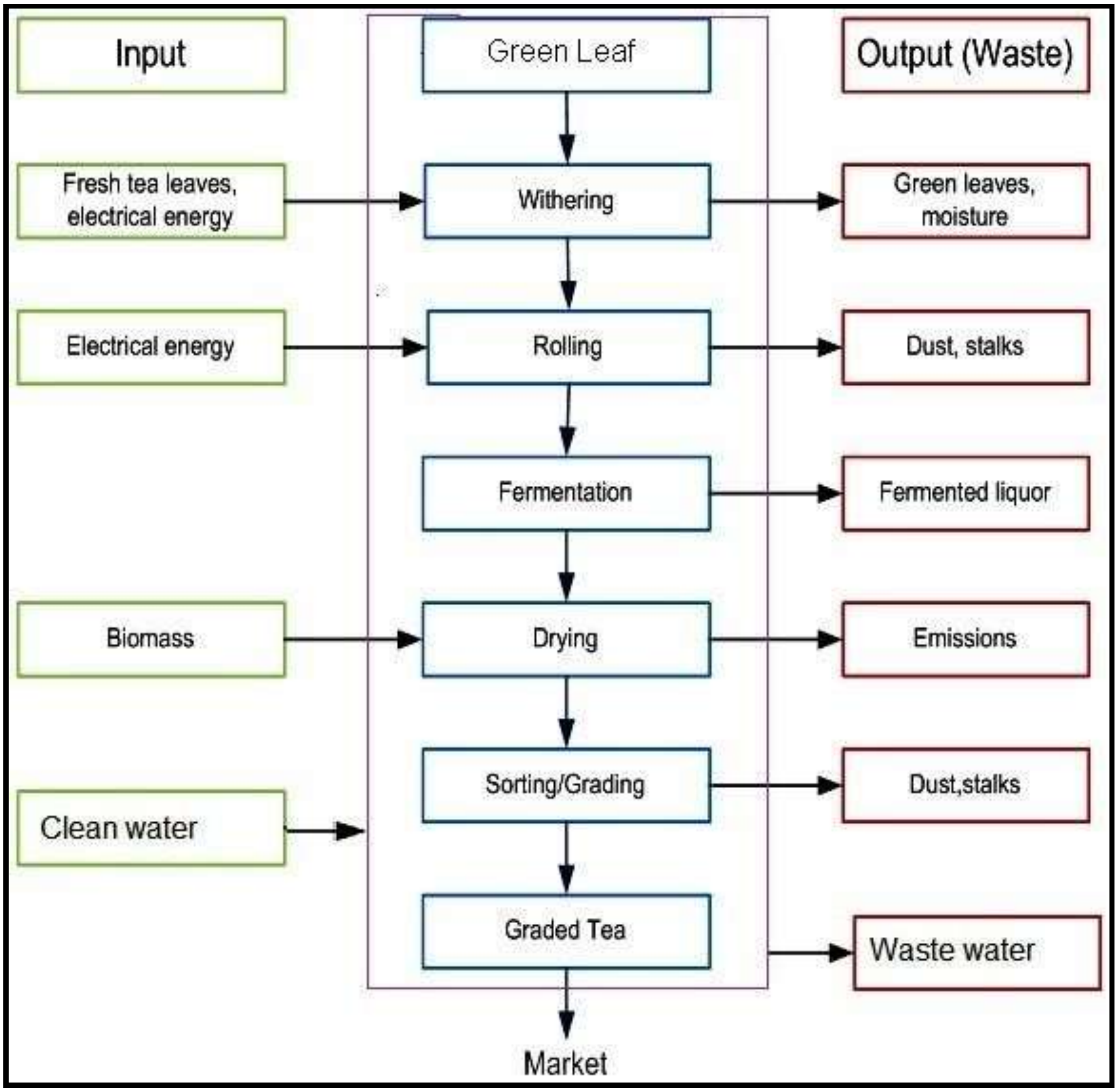


Figure 9: Schematic Diagram for Tea Processing and Wastes Generated. Source: Oirere (2015)

A field experiment conducted on fodder maize by altering the use of chemical, organic, and biofertilizer reported that the use of half fertilizer portion containing green compost and biofertilizer yielded the lowest expense (Jilani et al., 2007). Although higher biomass production was obtained from chemical fertilizer, the highest net profit was seen in the usage of biofertilizer with effective microorganisms or biological potassium fertilizer. NPK fertilizers produce rapid effects and they can achieve high yield in a short time, but biofertilizers are renewable and their effects last for a longer period with many additional benefits for plant growth (Shen, Z. et al 2015). The conversion of municipal solid waste into compost for seedling production was also found to have good economic potential. The substitution of peat with compost could reduce the cost of the substrates by up to 23%. This reduction could generate an increment of 2.9% in the business contribution margin for crops productions. Supply of compost is in abundance and stable as it is obtained as a by-product generated from solid waste, enabling the transformation of the compost to value-added fertilizers to be sold at a secure price (Jara-Samaniego et al., 2017). Hence, composting contributes tremendously in the efficient management of waste resources as well as adds economic value to waste by recycling the nutrient content and substrate components in the waste. Better economic prospects can be attained with the combination of bio and organic fertilizers together with chemical fertilizers to promote a sustainable crop production technology (Jilani et al., 2007). Owing to that, there is great economic potential in biowaste conversion, which can lead to a reduction in average costs of the growing media used for crops growth.

Mutai (2018) assessed waste management structures for tea factories in Kenya. This study was specifically carried out to establish the effectiveness of the waste management system in tea processing factories in Kenya with a case study of Nyansiongo tea factory. The study identified the types and sources of solid, liquid and thermal wastes generated during tea production mainly through observations, the identified solid wastes at every stage of tea production were then sampled and weighed and their weights recorded, the wastewater was also sampled and analysed empirically for Biochemical Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), pH and electrical conductivity, boiler data was also collected and analysed to determine the efficiency of the boiler. Solid waste in the Nyansiongo tea factory was found to be 0.01% of the total tea production. The highest amount of waste was generated from the withering stage due to spillages, while the least amount of waste was generated at the offloading area. Solid waste generated from the factory is poorly disposed; the waste is not segregated (different types of wastes are not disposed separately).

(Chowdhury et al., 2016) assessed the types of wastages that generated as a byproduct from tea processing industries in India. Quality and quantities of tea waste and their proper management or waste disposal method were determined in Terai and Duars region of West Bengal. A random cluster sampling technique was used in selecting 20 study sites, out of the 30 tea factories that are spread in four major tea producing districts namely foothills of Darjeeling, Jalpaiguri, Alipurduar and a part of Cooch Behar were performed. Primary and secondary data were documented during data collection, using questionnaires, interviews, observation and necessary photographs were taken. The study revealed that that effective management strategies would improve socio-economic status of tea garden workers as well as owners by utilizing this waste in poultry and fish feed, garden manure and caffeine extraction. Fibers from tea waste can be converted into different industrially implemented products like low-cost absorbent during removal of pollutants from waste water. Furthermore, the emergence of new technologies might utilize tea waste for the preparation of *n* triacontanol, which is a commercially valuable bio-nutrient and has important growth promoting activities of leaf primordia.

A field experiment was initiated at the Central Soil Salinity Research Institute, Karnal, India between 1994 and 1998 involving use of NPK fertilizers alone and in combination with green manure (Sesbania bispinosa) or farmyard manure (FYM) in a rice–wheat cropping sequence (Yaduvanshi, 2003). An attempt was made to evaluate the effect of the substitution of inorganic fertilizers with organic manures on yields of grain and nutrients, economy and soil fertility during 1997–98 and 1998–99. Application of NPK and its combination with green manuring and FYM increased the rice yield significantly. Applying inorganic fertilizers resulted in similar nitrogen use efficiency (NUE) in rice as compared with organic manures along with inorganic fertilizers, but NUE was increased in wheat by the residual effect of organic manures along with inorganic fertilizers. The responses of rice to the application of the full recommended amount of inorganic fertilizers (120 kg N, 26 kg P and 42 kg K/ha) and its combined use with green manure or 10 t/ha FYM and 150% recommended amount (180 kg N, 39 kg P and 63 kg K/ha) were 2. 98, 4. 27, 4. 10 and 3. 54 t/ha, respectively. Further, with green manure or 10 t FYM/ha in combination with 50% recommended amount, the mean rice yield (5. 8 t/ha) was similar to the yield (5. 5 t/ha) obtained from the 100% NPK recommended treatment. Application of green manure or 10 t FYM/ha thus saved 60 kg N and 13 kg P/ha inorganic fertilizer in rice. The residual effect of green manure or FYM plus the full recommended fertilizer amount (120 kg N, 26 kg P and 42 kg K/ha) was significantly greater than that of the full recommended amount of fertilizer. Addition of green manure or FYM resulted in higher removal in crops, increase of soil N, P, K and organic C, and reduced soil pH. Application of the full recommended amount of fertilizer only maintained the N, P and K status in soil. Higher profit was obtained when inorganic fertilizer was combined with organic manures.

Desert soil is one of the most severe conditions which negatively affect the environment and crop growth production in arid land. The application of organic amendments with inorganic fertilizers is an economically viable and environmentally comprehensive method to develop sustainable agriculture. Tanveer Ali Sial et al (2019) assess whether milk tea waste (TW) amendment combined with chemical fertilizer (F) application can be used to improve the biochemical properties of sandy soil and wheat growth. The treatments included control without amendment (T1), chemical fertilizers (T2), TW 2.5% + F (T3), TW 5% + F (T4) and TW 10% + F (T5). The results showed that the highest chlorophyll (a and b) and carotenoids, shoot and root dry biomass, and leaf area index (LAI) were significantly ($p < 0.05$) improved with all amendment treatments. However, the highest root total length, root surface area, root volume and diameter were recorded for T4 among all treatments. The greater uptake of N, P, and K contents for T4 increased for the shoot by 68.9, 58.3, and 57.1%, and for the root by 65.7, 34.3, and 47.4% compared to the control, respectively. Compared with the control, T5 treatment decreased the soil pH significantly ($p < 0.05$) and increased soil enzyme activities such as urease (95.2%), β-glucosidase (81.6%) and dehydrogenase (97.2%), followed by T4, T3, and T2. The findings suggested that the integrated use of milk tea waste and chemical fertilizers is a suitable amendment method for improving the growth and soil fertility status of sandy soils.

2.2 Chapter Summary

The chapter has outlined the concept of waste management and the significance of sustainable waste management. The chapter has also outlined the tea processing procedure as well as the types of waste generated throughout the process. Furthermore, the chapter has highlighted major knowledge gaps that wastes has traditionally been viewed as having no value. However, they can be recovered (or prevented from being lost) through greater efficiency and management at every stage of production and consumption. It has also been noted that responsible institutions pay little attention to different characteristics of waste, seasonal variations and future trends of waste generation. The next chapter presents the methodology employed in the study.

CHAPTER 3: MATERIALS AND METHODS

3.1. Introduction

This chapter presents the methodology that was adopted to assess the feasibility of on-site tea organic waste usage either for agricultural application in Mulanje District. The chapter provides the research design adopted, sample size and sampling techniques, Laboratory analysis of the collected solid waste samples as well as the analytical techniques. The chapter finally presents data quality and ethical considerations that were made.

3.2. Research design

For the purpose of assessing the feasibility of on-site tea organic waste usage either as an alternative or supplement to chemical fertilizers for agricultural application, the study adopted a quantitative approach as it emphasizes on objective measurements and the statistical, mathematical, or numerical analysis of data collected through polls, questionnaires, and surveys, to explain a particular phenomenon.

Study area

The research study was conducted in Mulanje district in the three tea factories of Lujeri estate *(Nsayama, Bloomfield and Lujeri)*

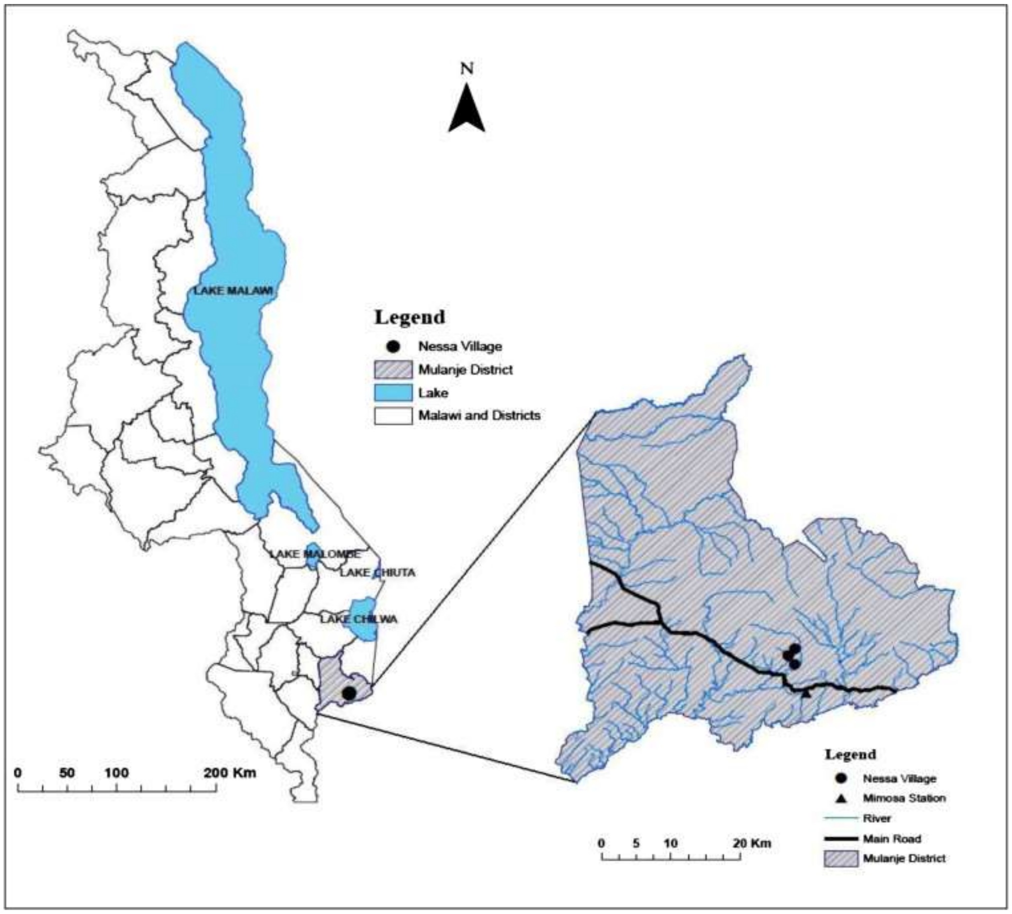


Figure 10: Study Site Map

3.3. Tea Waste Analysis

Samples were analyzed in triplicate for nitrogen, phosphorus and potassium. This section outlines the procedures and techniques in detail.

3.3.1. Sampling and sample size

A total of 27 samples of organic tea waste generated from the factories were collected from these disposal sites of the three processing facilities namely Nsayama, Lujeri and Bloomfield. To collect waste samples following AOAC standards, gathering tools such as gloves, sampling containers, a soil auger or trowel, measuring tape, and labels were prepared. A random zigzag pattern was employed to ensure randomness, moving systematically across the area to select sampling points. At each point, waste from 30-60 cm depth was collected using marked tools, maintaining consistency in material collection. The samples from different points were combined or mixed to create a representative composite sample, addressing variations in waste composition. Package composite samples were labelled and packaged securely in containers, preventing contamination, and stored them in controlled conditions to preserve their properties during transport to the lab for analysis. Analysis of samples was done at the laboratory according to AOAC (2005) Official Standard Methods of Analysis.

3.3.2. Materials and Reagents

All reagents used were of high-grade quality labelled AnalaR or AR sourced from trusted suppliers. Potassium chloride, ammonium metavanandate, ammonium molybdate, perchloric acid, copper sulphate anhydrous, and potassium di-hydrogen phosphate were sourced from Saarchem (South Africa). Other reagents such as sulphuric acid, salicylic acid, zinc dust, potassium sulphate anhydrous, mixed indicator, ethanol, nitric acid and sodium carbonate were bought from Associated Chemical Enterprise (South Africa)

3.3.3. Determination of Nitrogen content in Tea Solid waste

According to (AOAC, 2005) the micro - Kjeldahl Method is based on the conversion of nitrogen of nitrogenous substances into ammonia by boiling with concentrated sulphuric acid, which is fixed by excess of the acid as ammonium sulphate. The latter is determined by adding an excess of caustic alkali to the solution after digestion with the acid, and distilling off the liberated ammonia into boric acid after which it is quantified by nitration.

Calculations and Reporting

The percent total nitrogen (%N) was calculated using the following formula:

$$\% N = \frac{(a)(b)(14)(100)V_0}{C*1000*V_1} \qquad (1)$$

Where:

a = Concentration of acid,

b = Volume of standard acid used (ml) for sample minus blank,

V_0 = Final dilution after digesting the sample,

V_1 = Aliquot used during distillation,

C = Sample weight.

3.3.4. Determination of Phosphorus content in tea solid waste

The percentage (%) of phosphorus in tea solid waste was determined using Vanadate / Molybdate UV-Visible Spectrophotometric Method and this is in accordance to (AOAC, 2005) standards. The method is based on the reaction of phosphates with molybdate in the presence of vanadate to form yellow phosphovanadomolybdate. The intensity of the yellow colour is proportional to phosphate concentration in the sample and is measured at 400nm.

A quantity of about 1g sample of tea wastes was incinerated in a muffle furnace (Model CSF 12/3, Carbolite furnaces), at 600^0C for 4 hours, 20 ml of HCl (1+3) were added plus several drops of HNO_3. The contents were brought to boiling, cooled and transferred to 100 ml volumetric flask. The mixture was diluted to volume with distilled water. A volume of 20ml of digested sample was placed in 100ml volumetric flask, 20ml of color solution added and the mixture was diluted to 100ml. If the samples contained phosphorus yellow color was observed and the intensity of the color, which was proportional to the concentration of phosphorus in the solution, was read on UV-Visible Spectrophotometer (Model 1100RS, UNICO, United States) as absorbance at a wavelength of 400 nm

The concentration of P (ppm) in samples was calculated using the formula ($y = 0.0772x$) above from the calibration curve (curve of working standards versus their concentrations), Where $y =$ absorbance of the sample (s) in question and 'x' $=$ the required concentration of the samples. The actual concentration of phosphorus was obtained by using the formula below:

$$\% P = \frac{\text{P in ppm(curve) x final dilution volume after digestion x dilution factor during analysis}}{\text{Mass of sample (g) x 10,000}} \qquad (2)$$

3.3.5. Determination of potassium content in tea solid wastes

The percentage (%) of potassium was determined using Atomic Absorption Spectrophotometric method in accordance to AOAC (2005). The principle behind the method is that metals in solution are determined by atomic absorption spectrophotometer. It is done by exiting free atoms in aflame by narrow spectrum of characteristic energy from the light source. The free atoms absorb the energy from the source and the decrease in energy *(Absorption)* is then measured. Absorption is proportional to the concentration of free atoms in the flame or to make it simple, it is proportional to the concentration of required metal element in the sample.

About 1.0 gram was accurately weighed into a pyrex beaker. 10 mL of nitric acid (HNO3) were added and the contents were let to soak thoroughly. 3 mL of 60% perchloric acid (HClO4) were also added and thoroughly mixed again. The mixture was heated gently on a hot plate until frothing ceases. Heating continued but this time strongly until HNO3 almost evaporated and white fumes appeared. When charring ceased after several additions of HNO3, the digest appeared pale yellow to colourless and the solution was deemed to have digested completely. The digest was diluted with distilled water to 100ml of volumetric flask.

The Atomic absorption spectrophotometer (GBC 932 AA, GBC Scientific Pty LTD, Australia) was turned on and the hallow cathode lamp for potassium inserted in its socket number. The machine was turned on for 15 minutes in order to warm it up.

Lamp current for potassium was 6.0 mA, flame type was air-acetylene and the wavelength was 766.5nm with a slit width of 0.5nm. Fuel (Acetylene) and air was supplied from acetylene cylinder and air compressor respectively. Operation of the machine was done according to the manufacturer's manual. The standards were allowed to run first (for calibration curve) followed by the samples. The absorbance and concentration of the samples were read and recorded. The concentration of samples was calculated using the formula ($\boldsymbol{y = 0.0682\,x}$) from the calibration curve which were prepared in the laboratory (curve of working standards versus their concentrations), Where $\boldsymbol{y}$ = absorbance of the sample (s) in question and '$\boldsymbol{x}$' = the required concentration of the samples. The actual concentration was arrived at after considering dilution factor as below:

$$K\ (ppm) = AAS\ reading * dilution\ after\ digestion * dilution\ during\ Analysis\ (10\ times) \quad (3)$$

3.4. Calculating Nutrient Content Equivalent

Nutrient content equivalent is the amount of organic fertiliser (tea waste) that can supply nutrients (N or P) equivalent to what an equivalent quantity of chemical fertiliser can supply. According to (IOWA, 2011) application rates for organic fertiliser are primarily based on N or P needs for crop production. For the purpose of this study, the calculations were based on Nitrogen as indicated below:

$$Q_{OF} = \frac{Q_{NCF}}{Q_{NOF}} * 100 \qquad (5)$$

Where:

Q_{OF} *(Measured in kg)* is the quantity of organic fertiliser that would supply Nitrogen equivalent to what 100kg of chemical fertiliser can supply.

Q_{NCF} Is the quantity of nitrogen supplied by 100kgs of chemical fertiliser: based on T-compound nutrient composition.

Q_{NOF} is the quantity of nitrogen supplied by 100kgs of organic fertiliser: *based on the proportion of nitrogen as calculated in the lab analysis.*

3.5. Financial Analysis

Financial analysis is a critical process that involves the evaluation of a company's financial statements, ratios, and key performance indicators to assess its financial health and performance. It enables stakeholders, including investors and analysts, to gain insights into the company's profitability, liquidity, solvency, and overall financial stability (Brigham & Houston, 2019). By examining metrics such as the debt-to-equity ratio, current ratio, and return on equity, financial analysis helps identify the company's ability to manage its resources, generate revenue, and meet its financial obligations. Additionally, financial analysis facilitates comparisons with industry benchmarks and competitors, aiding in the identification of areas of strength and weakness within the company's financial structure (Palepu et al., 2019). This data-driven process is crucial for making informed investment decisions and strategic business choices.

A structured interview form/checklist was used for collecting other quantitative data which included monthly solid waste generation, fertiliser use and application rates and prices for financial analysis.

The financial feasibility was analysed using the cost saved approach. This approach refers to a methodology that assesses the economic benefits of a particular investment or decision by quantifying the potential reductions in costs that would be achieved through its implementation. This approach involves identifying and evaluating expenses that could be eliminated or minimized as a direct consequence of the proposed action. By estimating the difference between existing costs and the projected costs after the implementation of the investment, the cost saved approach provides a comprehensive understanding of the potential financial gains and efficiencies that can be derived (Ross et al., 2019). This approach assists decision-makers in evaluating the viability and potential profitability of a given investment or decision. The approach was also applied in the agricultural sector to assess the financial impact of adopting integrated pest management (IPM) strategies. For instance, in rice cultivation, the implementation of IPM involves reducing chemical pesticide applications through the use of natural predators and alternative pest control methods. Researchers utilized the cost saved approach by estimating the potential decrease in pesticide purchases and application costs, along with the associated environmental benefits and potential yield improvements (Muniappan et al., 2015). By comparing these projected cost savings with the costs of implementing IPM practices, farmers were able to make informed decisions regarding the adoption of sustainable pest management techniques, taking into account both financial benefits and ecological considerations.

The analysis was done using the equation below:

$$CS = \sum_{i=1}^{n=3} (C_{NFCFi} - C_{NPCFi}) \tag{6}$$

Where:

CS is the cost saved of using organic fertiliser *(tea waste)*

C_{NFCFi} the cost of nitrogen from fully using chemical fertiliser for factory i

C_{NPCFi} the cost of nitrogen from partially using chemical fertiliser for factory i which is given by:

$$C_{NPCFi} = P_N(Q_{NCF} - Q_{ANOF}) \tag{7}$$

Where

P_N is the current market price of a kg of nitrogen calculated as:

$$P_N = \frac{Market\ price\ of\ a\ 50kg\ Bag\ of\ chemical\ fertiliser}{Amount\ of\ Nitrogen\ in\ a\ 50kg\ bag\ of\ chemical\ fertiliser} \tag{8}$$

Q_{NCF} is the required amount of nitrogen from chemical fertilizer for plant development based on the recommended rates application rates and nutrient content.

Q_{ANOF} is the available amount nitrogen from organic fertiliser as calculated based on equation *(5)*

3.6. Data analysis

Descriptive statistics were used to describe patterns of the data. Cross tabulations and graphs were used to provide composition of plant nutrients (Nitrogen, potassium and phosphorus) in solid tea waste generated during Tea processing. Non parametric tests were used because normality assumptions of the data were violated to warrant parametric tests. Kruskal Wallis test analogous to

One-way ANOVA was used to determine the significance of the composition of plant nutrients. The comparison of plant nutrients (NPK) from solid tea waste and chemical fertilizer was made by using Mann Whiney U test analogous to Independent Samples T test.

3.7. Ethical considerations

Ganiza and Sibanda (2015) states that upholding of research ethics is considered paramount to successful compilation of findings and results. Ganiza and Sibanda (2015) further calls for ethical consideration procedures especially when dealing with human subjects. There was adherence to ethical standards throughout the data collection process. The first step was to solicit informed consent from the estate manager and then voluntary participation from the staff working inside the tea processing factory who took the team through the whole process of tea production to appreciate the wastes produced at each and every stage. The estate workers were briefed about voluntary participation and that they would withdraw at will at any point of the interview and data collection process. They were also briefed that the study would not collect personal information and that any personal information (to ensure anonymity and confidentiality) would be de-linked from the data and the report during data analysis and report writing, respectively. Prior to obtaining consent, the factory managers were provided with sufficient knowledge about the purposes and intentions of the study and were assured that both the interview and questionnaire data would remain confidential.

CHAPTER 4: RESULTS AND DISCUSSION

4.1. Introduction

The chapter first presents and discusses the technical analyses of Tea Waste for nitrogen, phosphorus and potassium. The chapter then presents and discusses the nutrient content equivalent analysis for organic tea waste. Finally, the chapter discusses the financial and economic analyses of tea waste utilization.

4.2. Quantity of tea waste generated

The results of the quantity of solid tea waste generated during tea processing have been presented in Table 1. The results show that Lujeri factory generated more solid tea waste (457.2 kgs per hectare per year) as compared to Bloomfield (411.6 kgs per hectare per year) and Nsayama (407.6 kgs per hectare per year) tea estates. Additionally, the results indicate that quantity of solid tea waste generated during tea processing was found to be 425.4 kgs per hectare per year which was an average Lujeri, Bloomfield and Nsayama tea estates, respectively.

Table 1: Quantity of solid tea wastes generated

Sample	Average Quantity (Kgs/ha/yr)
Lujeri	457.2
Bloomfield	411.6
Nsayama	407.6
Overall Average	425.4

This finding is higher than what a similar study found in Kenya. A study on the evaluation of waste management systems for tea factories in Kenya found that on average tea factories generated 487.7 kgs of tea waste per six months as measured in various stages of tea production (Oirere, 2015). This is tea waste generated per entire factory unlike the waste generated per hectare per year in Malawi tea factories. This implies that Malawi tea factories generate more tea waste by far when compared with similar factories in the Sub-Saharan Africa region. However, a study by Taulo & Sebitosi (2016) corroborates with the findings of this study that Malawian tea factories generate a lot of tea waste. The analysis of their study found that Malawian tea factories generated as much as 0.68% of solid tea waste as a percentage of total production. Taulo & Sebitosi (2016) noted that the highest amount of organic tea waste is produced at withering that accounts to as much as 0.5% of the total solid tea waste. This finding is also comparable to findings in literature that found that the highest tea waste in generated in withering. For example, a study by Oirere (2015) found that as much as 49.7% of total solid tea waste occurred at withering stage. Another study by Kola (2014) found that 71% of the total solid tea waste was produced at withering stage. One reason for the discrepancy in volumes of tea waste could possibly be the nature and designs of tea factories in Malawi and those within the region coupled with the different sustainability initiatives aimed at reducing waste implemented at factory level. One of the recommendations by the study by Oirere (2015) is the redesign of the withering troughs to reduce the level and amount of wastage during this stage in the production process.

4.3. Composition of plant nutrients in solid tea wastes and T-compound

This section presents and discusses results of triplicate analysis for nitrogen, phosphorus and potassium. For the purpose of comparing the results, T-compound[1] fertilizer was used.

4.3.1. Nitrogen content in tea waste and fertiliser

The results of the nitrogen have been presented in Table 2. The results show that the Nitrogen content from the sample from Lujeri, Bloomfield and Nsayama were 3.32% 3.16% and 3.11% respectively. Furthermore, results indicate that overall, nitrogen content in tea waste was found to be 3.19% which was an average Lujeri, Bloomfield and Nsayama tea estates, respectively. This conforms to what Qiao et al. (2019) found in their research. In an attempt to explore the chemical composition of the surface of unmodified and modified tea waste, Qiao et al. (2019) conducted an EDS analysis. Results from this EDS analysis also showed Nitrogen as one of the main elements found in tea wastes. The result is lower than the *24.82* % that is contained in T-compound, a chemical fertiliser used in tea production. Furthermore it is lower than what (Davenport, 2019) reported to be the nitrogen content in Tea Leaves (grounds) to be 4.15%.

[1] According to OPTICHEM (2020) T-compound fertilizer has the following proportions *N:P:K-24.69:5.21:5.01*.

Table 2: Nitrogen Percentages in Tea Wastes and T-compound

Sample	Tea Waste (%)	T-Compound (%)
Lujeri	3.32	24.86
Bloomfield	3.16	24.75
Nsayama	3.11	24.84
Overall Average Percentages	3.19	24.82

Besides nitrogen being one of the main elements constituting tea wastes naturally, adsorption of it from the surrounding could also account for greater percentage Qiao (2019). This could be validated by the research done by Qiao (2019) who highlighted that these tea wastes adsorbed nitrates and phosphates from the medium of concern in their research, both of which are species of nitrogen and phosphorus respectively. This could cement availability of significant amount of nitrogen in the tea wastes, a thing that is in agreement to this study. The significant difference in the percentages of nitrogen and phosphorus and difference in the percentage of nitrogen and potassium in both tea wastes and T-compound is observed. However, the percentage of nitrogen in tea waste is significantly lower than the percentage of nitrogen present in T-compound, a thing that is paramount to the growth of plants because excessive availability of nitrogen is detrimental to the growth of plants and can easily cause undesirable effects to the environment as a whole (Mikkelsen & Hartz, 2008). Insufficient availability of nitrogen in the soil medium is also not conducive condition for plants because it results in inefficient water use, poor quality low yield and low protein levels. As highlighted by Mikkelsen and Hartz (2008), plants acquire this nitrogen element in several species, but the most predominant ones being through Ammonium ion (NH_4^+) and Nitrate ion (NO_3^-).

In addition, Igbal Khan et al. (2007) found that green tea contained 7.55% Nitrogen. A study by Chen et al. (2014) found that applied organic fertilizers has enormous potential to reduce the loss of nitrogen (N) and phosphorous (P) and maintain tea yields. In this regard, their study suggested the cultivation of a combination of legumes and non-legumes and reducing the use of N chemical fertilizers that decrease the loss of soil N and benefit crop yields (Chen et al. 2014).

4.3.2. Phosphorus content in tea waste and fertiliser

The results of the phosphorus have been presented in Table 3. The results show that the phosphorus content from the sample from Lujeri, Bloomfield and Nsayama were 0.52%, 0.58% and 0.64%, respectively. Furthermore, the results indicate that overall, phosphorus content in tea waste was found to be 0.58% which was an average for Lujeri, Bloomfield and Nsayama tea estates, respectively. This is lower than the 5.02% that is contained in T-compound, a chemical fertiliser used in tea production. Furthermore, it is lower than what (Davenport, 2019) reported to the phosphorus content in Tea Leaves (grounds) to be 0.62%.

Table 3: Phosphorus Percentages in Tea Wastes and T-Compound

Sample	Tea Waste (%)	T-Compound (%)
Lujeri	0.517	4.97
Bloomfield	0.583	5.07
Nsayama	0.644	5.01
Overall Average Percentage	0.581	5.02

Chen et al. (2014) found that applied phosphorus changes the phosphorus stock in soils and influences the amount of phosphorus that is available for plants. Furthermore, applied organic phosphorus helps to increase the available phosphorus in the topsoil and deeper soil layers (Chen et al. 2014). However, Chen et al. (2014) were quick to point out that the excessive organic phosphorus might change soil texture and the adsorption capacity of soils, and reduced adsorption capacity and increased porosity may result in higher soil erosion and phosphorus loss, which increases the risk of water pollution.

Chen et al. (2014) introduced low-P fertilizers in their study as a new best management practice that is similar to the rational fertilizer method, but is specifically focused on the problem of excessive phosphorus. Traditional fertilizers were modified to include less than half of the usual amount of phosphorus and were then applied to the low-phosphorus field (Chen et al.,2014). For instance, the Taipei Feitsui Reservoir Administration and the Tea Research and Extension Station cooperated with the Taiwan Fertilizer Company to manufacture low phosphorus fertilizers for tea cultivation (Chen et al., 2014). This really augurs well for organic tea waste since the levels of phosphorus are already found in low percentages which serves as an optimum tea plant requirement.

Chen et al. (2014) demonstrated the results of applying low phosphorus and regular phosphorus fertilizers and concluded that low phosphorus fertilizers help to improve the quality of the effluents and brewed tea at the study sites. However, they found no significant differences in the agricultural characteristics and yield between the low phosphorus and regular phosphorus fields. The taste of the manufactured tea from the low phosphorus field was judged to be better, because the brewed tea contained more theanine (Chen et al., 2014).

4.3.3. Potassium content in tea waste and fertiliser

The results on technical analysis of potassium have been presented in Table 4. The results show that the potassium content from the sample from Lujeri, Bloomfield and Nsayama were 0.44%, 0.45% and 0.39%, respectively. Furthermore, the results indicate that overall, potassium content in tea waste was found to be 0.43% which was an average for Lujeri, Bloomfield and Nsayama tea estates, respectively. This is lower than the *5.00*% that is contained in T-compound, a chemical fertiliser used in tea production. Furthermore, it is almost the same proportion as what (Davenport, 2019) reported to the potassium content in Tea Leaves (grounds) to be 0.44%. Singh and Pathak (2018) noted that Tea plants require comparatively higher quantity of potassium for production and quality of produce. Potassium is the second major nutrient for tea plant after nitrogen (Singh & Pathak, 2018).

Table 4: Potassium Percentages in Tea Wastes and T-Compound

Sample	Tea Waste (%)	T-Compound (%)
Lujeri	0.4397	5.00
Bloomfield	0.4498	5.01
Nsayama	0.3889	4.99
Overall Average Percentage	0.4261	5.00

4.4. Nutrient content equivalent analysis for tea waste

Table 4.6 presents results of the nutrient content equivalent analysis. Results indicate that under normal circumstances amount of T-compound fertiliser applied in tea fields is 204500 Kg, 193750Kg and 117750 Kg for Lujeri, Bloomfield and Nsayama, respectively at an application rate of [2]250 Kg/Ha. This makes a total of 516000 Kg of T-compound fertiliser applied for the three tea estates. Furthermore, based on the nutrient content of T-compound fertiliser, it entails that a total of 127400 Kg of nitrogen is supplied to tea fields disaggregated as 50491 Kg, 47837 Kg and 29073 Kg for Lujeri, Bloomfield and Nsayama, respectively. Additionally, results indicate that a total of 885000 Kg of solid tea waste is available for use from the three Tea Estates. The N: P: K-content of tea waste found to average 3.19:0.58: 0.43, it implies that a total of 28232 Kg of Nitrogen is available for use from tea waste disaggregated as 11931 Kg, 10176 Kg and 6125 Kg for Lujeri, Bloomfield and Nsayama tea estates, respectively. Furthermore, based on the nutrient content analyses a total of 22.2% can be supplied by the tea waste.

Nutrient content was compared within Waste and the box plot highlights the differences amongst them (Figure 1). The waste had the highest Nitrogen content (mean = 3.19) while Phosphorus and Potassium had 0.58 and 0.43 respectively (Table 5).

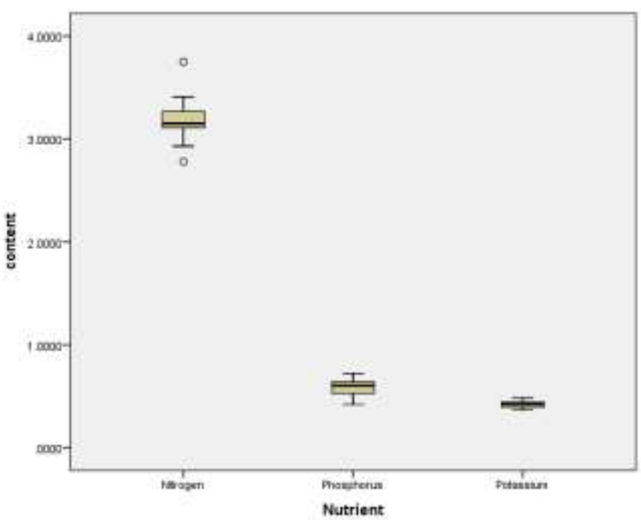


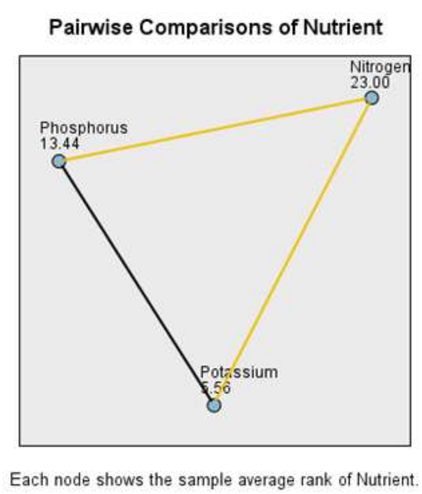
Figure 11: Nutrient content

Table 5: Summary statistics for nutrient content in Waste

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Nitrogen	9	3.192222	.2782435	.0927478	2.978345	3.406099	2.7800	3.7500
Phosphorus	9	.581556	.0927444	.0309148	.510266	.652845	.4190	.7230
Potassium	9	.426000	.0405986	.0135329	.394793	.457207	.3680	.4810

The comparisons of nutrients were made within Waste to determine if the difference in nutrient content was significant across the three nutrients. The Krustal Wallis test was performed under the null hypothesis that the distribution of content composition in the same in Nitrogen, Phosphorous, and Potassium. The results show that the distribution of content composition in different in Nitrogen, Phosphorous, and Potassium at 0.05 significance level *(N= 27, Test statistic = 21.8, df = 2p-value < 0.001).*

Pairwise comparisons were made to determine the which pairs of nutrients were significant. Nitrogen content was significantly different to Potassium and Phosphorous but Potassium and Phosphorus were not significant (Figure 12).



Sample1-Sample2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj.Sig.
Potassium-Phosphorus	7.889	3.741	2.109	.035	.105
Potassium-Nitrogen	17.444	3.741	4.663	.000	.000
Phosphorus-Nitrogen	9.556	3.741	2.554	.011	.032

Figure 12: Pairwise comparisons of Plant nutrients

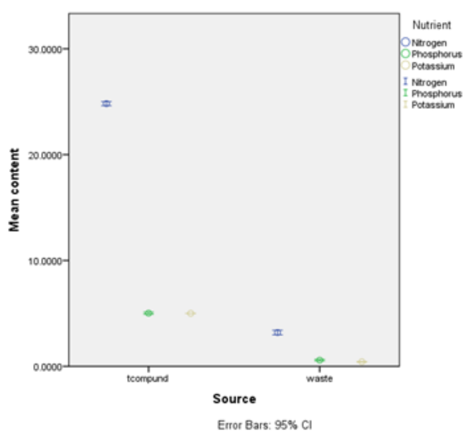
4.5. Comparisons of plant nutrients *(N: P: K)* between solid tea waste and chemical fertilizer

The comparisons were made between Waster and Chemical fertilizers. Chemical fertilizers seem to have higher meant content of Nitrogen, Phosphorus and Potassium compared to Waste as shown in Table 6. Nitrogen content was higher in Chemical fertilizers than in Waste and this trend is observed for Phosphorus and Potassium (Table 6).

Table 6: Summary statistics for plant nutrients in Waste and Tcompound

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
tcompund-N	9	24.819715	.2556111	.0852037	24.623235	25.016195	24.5391	25.3487
tcompound-P	9	5.020275	.1279978	.0426659	4.921887	5.118662	4.9024	5.3300
tcompund-K	9	5.004168	.0079419	.0026473	4.998063	5.010273	4.9898	5.0201
Waste-N	9	3.192222	.2782435	.0927478	2.978345	3.406099	2.7800	3.7500
Waste-P	9	.581556	.0927444	.0309148	.510266	.652845	.4190	.7230
Waste-K	9	.426000	.0405986	.0135329	.394793	.457207	.3680	.4810

Comparing the plant nutrients in Waste and Chemical fertilizers the pairwise comparisons show that the all the plant nutrient contents (N:P:K) were significantly higher in Chemical Fertilizers than Waste (p-value <0.001; p-value = 0.035; p-value = 0.004) at 0.05 level of significance.



Sample1-Sample2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj.Sig.
Waste-K-tcompund-K	31.444	7.416	4.240	.000	.000
Waste-P-tcompound-P	22.556	7.416	3.041	.002	.035
Waste-N-tcompund-N	27.000	7.416	3.641	.000	.004

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is .05.

Figure 13: Comparisons of plant nutrients between tea waste and T compound

Low Phosphorus and Potassium percentages recorded in tea wastes as compared to the same elemental percentages in T-compound validates the argument that tea waste could be a significant alternative to the chemical fertilizers because excessive availability of Potassium has proven to be detrimental to the soil characteristics. Potassium is mostly present in nature in the form of Potassium halides, and when these Potassium halides are present in extremely large quantities, they harden the soil which interferes with the growth of the plants. Such scenarios have been observed and reported for all the salts when present in extremely large quantities in soil. With tea wastes registering relatively low percentages of Potassium, assurance on the insignificant percentages of Potassium halides is guaranteed implying favourable pH for the plants. Potassium Chloride, when subjected in water, has a tendency to dissociate and form K^+ and Cl^- . K^+ are adsorbed onto the surfaces of the soils due to their strong affinity for negatively charged surfaces of the soils; thus, these difference in charges create an ionic attraction which results in significant percentage of K^+ getting attached onto the surface of the soil particles (Li et al., 2020). The remaining $Cl^-$are left wandering within the water medium. Over-fixation of these potassium ions is detrimental to the growth of the plants. Scientific theories generated through research outcomes reveal that the nitrogen is present mostly in the form of NO_3^- or NH_4^+. Both of these species are paramount in plant development. An increase in NO_3^- is associated with an increase in K^+ uptake in the plants. This is because nitrate ions have an opposite charge to potassium ion which facilitates an ionic attraction between them, thus, eventually extracting significant quantity of potassium ions from the soil (Sitienei, 2013).

However, excessive presence of NH_4^+ within the soil medium or if extracted into the plants from the soil, has the tendency to affect uptake of potassium ions due to the similarity of the charges which repel each other and also compete for the same nitrate ion surfaces (Sitienei, 2013). Conversely, it could be stated that excessive amount of potassium ions can affect the uptake of ammonium ion and deprive plants that require ammonium more (Sitienei, 2013). The positively charged potassium ion (K^+), when present in extremely large amounts, affects NH_4^+ uptake into the plants since they are both of the same charge. The low percentage of potassium in tea waste as revealed by the study cements the fact that tea waste might as well be a better alternative to chemical fertilizers (T-compound) due to their reasonable percentages of potassium that will not resort to over-fixation which might affect uptake of ammonium ions.

This therefore implies that 22.2% of required nitrogen for Tea production can be supplied by solid Tea waste. With regard to the estates, Lujeri has the highest proportion as it can supply 23.6% of the required nitrogen with the tea waste that it produces followed by Bloomfield which can supply 21.3% of nitrogen from the solid Tea waste that it produces. Sayama can supply up to 21.1% of the required nitrogen that it supply. The results also reveal that based on the nitrogen content, the application rate for the tea waste is 1935.0 Kg/Ha. These findings simply cement the findings from FAO (2015); IOWA (2011); Pandyaswargo & Premakumara (2014) and Rahman et al. (2006) who have argued and indicated that plant waste is a feasible source for plant nutrient. In fact, FAO (2015) argued that such plant waste can be used to supplement or compliment chemical/ inorganic fertilisers. Furthermore, these findings underscore the significance of organic fertiliser. FAO (2015) argues that although organic waste or manure provides all the nutrients that are required by plants but in limited quantities, it helps in maintaining the C: N-ratio in the soil and also increases the fertility and productivity of the soil. Furthermore, it improves the physical, chemical and biological properties of the soil as well as the structure and texture of the soils (FAO, 2015). More importantly is the fact that compost increases the water holding capacity of the soil and it minimises the evaporation losses of moisture from the soil. Additionally, FAO (2015) argues that due to increase in the biological activity, the nutrients that are in the lower depths are made available to the plants.

Figure 14: Nutrient Content Equivalent

Variables	Description	Tea estates			
		Lujeri	Bloomfield	Nsayama	Overall
Area (Ha)		818	775	471	2064
Application Rate (Kg/Ha)		250	250	250	250
Amount of fertiliser applied (Kg)		204500	193750	117750	516000
Amount of Nutrient Content from T-Compound (Kg)	*N (24.69%)*	50491	47837	29073	127400
	P (5.21%)	10655	10095	6135	26884
	K (5.01%)	10246	9707	5900	25852
Amount T-Compound per Kg of N	*A Kg of N from T-Compound*	12.3	12.3	12.3	12.3
Amount of N per Ha from T-Compound	*5*12.35*	61.7	61.7	61.7	61.7
Amount of nutrients in 50 Kg Bag of T-Compound	*N (24.69%)*	12.3	12.3	12.3	12.3
	P (5.21%)	2.6	2.6	2.6	2.6
	K (5.01%)	2.5	2.5	2.5	2.5
Amount of Tea waste	*(Kg)*	374000	319000	192000	885000
Amount of Nutrients from Tea Waste Available	*N (3.19%)*	11931	10176	6125	28232
	P (0.58%)	2170	185	1114	5133
	K (0.43%)	1608	1372	826	3806
Percentage of Nitrogen from Tea Waste		23.6	21.3	21.1	22.2
Amount of Tea Waste containing 1Kg of N (Kg)	*A Kg of N from Tea Waste*	31.3	31.3	31.3	31.3
Tea Waste Application Rates (Kg/Ha)	*N-requirement supply per Ha*	1935	1935	1935	1935

4.6 Financial feasibility of tea waste utilisation

Table 4.6 presents results of the financial feasibility analysis for tea waste utilisation. Results indicate that the price of a Kg of nitrogen costs $2.8. This is based on the prevailing market price of T-compound fertiliser used in tea production. Results further reveal that a total of 28,232 Kgs of nitrogen is available from tea waste aggregated from the three sampled estates as 11,931 Kgs, 10,176 Kgs and 6,125 Kgs for Lujeri, Bloomfield and Sayama tea estates, respectively. This entails that at the nitrogen price of $2.8/Kg, a total of gross value of $79,161.14 worth of nitrogen is available from tea waste disaggregated as $33,453.41, $28,533.79 and $17,173.94 for Lujeri, Bloomfield and Sayama tea estates, respectively. There are some caveats and limitation to this analysis. Due to the unavailability of some critical data and comparability of such data, the figures presented above present savings that would be made in gross value or gross terms. Ideally, this should have involved all the minor costs involved in organic waste such as transportation, labour et cetera. These costs are bundles within the estate activities thereby making it difficult to isolate the unit costs. For example, the same worker that applies the organic manure does other unrelated work activities who wage is paid as a lumpsum. Similarly, the same transport, that carry the organic waste/manure also transport other estate items concurrently. Furthermore, some estates such as Lujeri use a plane to apply its fertilizer the cost of the type of fertilizer application was not available at the time of data collection. Nonetheless, in value terms, activities involved in the application of the inorganic fertilisers cost more than the activities involved in the application of the tea waste. The results represents the gross cost saved for using tea waste as organic fertiliser. An economic analysis study by Neem et al. (2006) found that ultimately the net benefit from the use of organic manure was higher that fields that were used with inorganic fertilizers. This further entails that 22.2% of the gross cost of fertiliser can be saved by simply utilizing tea waste. Additionally, it implies that the cost saved are the resources freed up for other uses: for instance, this is the amount that can be invested in other portfolios of higher leverage which translates into win-win situation for the business. These findings are in agreement with what Pandyaswargo & Premakumara (2014) and Rahman et al. (2006) who argued that plant waste provides the agricultural sector with an opportunity to save costs and free up some resources for their other needs.

The economic and financial disadvantages found and reported in other studies do not outweigh the advantages of using organic fertilizers including tea waste organic fertilizers in the long term. For example, Keplingerand & Hauck (2006) noted that although the agronomic value of manure application is well established, its per ton value is low compared to commercial fertilizer. The low va1ue:mass ratios of manures result in higher application and transportation expense than for equivalent nutrient applications from commercial fertilizers (Keplingerand & Hauck, 2006). Furthermore Keplingerand & Hauck (2006) indicated that, like other commodities with low value:mass ratios, high transportation costs effectively limit the distance that manure can economically travel, resulting in localized manure markets. Keplingerand & Hauck (2006) found that demand for manure to supply crop nutrient requirements is spatially constrained and is a function of crop nutrient requirements. Manure supply, however, is largely tied to meat production decisions, because manure is a by-product of animal production. The by-product nature of manure in combination with structural changes in meat production has resulted in dramatically larger supplies of manure in production regions, irrespective of the capacity of crops in proximity to production to utilize manure nutrients.

Keplingerand & Hauck (2006) claimed that when supplies of manure become large, its value falls and an incentive is created to apply manure at rates exceeding crop requirements or to otherwise dispose of manure as inexpensively as possible, despite negative externalities.

The other cited downside of organic manure is that environmental degradation resulting from manure application being largely attributed to applications of manure nutrients in excess of amounts recommended to meet crop requirements (Keplingerand & Hauck, 2006). Additionally, when applied at greater than agronomic rates, excess nitrogen (N) may leach into groundwater, causing potential human toxicity, or be transported to coastal waters, resulting in eutrophication, while runoff of phosphorus (P) from cropland can cause eutrophication of fresh waters (Keplingerand & Hauck, 2006).

Keplingerand & Hauck (2006) concluded that land suitable for manure application is an important element in manure utilization but is very region- and site-specific. The ability of manure application equipment to access and fertilize cropland is often restricted by excessive slope or other physical factors (Keplingerand & Hauck, 2006). Keplingerand & Hauck (2006) study model concluded that increasing the ratio of land using manure increases manure value while reducing excess phosphate application.

Jour et al. (2013) in the study titled "Evidence for Generating High Margin Profit by Cost Cutting of Sustainable Agriculture Farming Input" presented evidence on how the farmers were able to generate high margin profit based on natural farming methods including the use of organic manure. They argued that the use of sustainable inputs presents an opportunity for the farmers to adopt fully sustainable use of organic inputs (Jour et al., 2013).

Jour et al. (2013) highlighted several advantages of natural farming that included potential increase of profit in terms of reducing production cost by 30 percent and use of available local input materials which are much cheaper; and boosting productivity three to four times more than conventional farming. Furthermore, they found that it is well- known that the products are safe for consumption because input materials are sustainable do not use synthetic chemical inputs (Jour et al., 2013).

Jour et al. (2013) reported that the majority of the farmers admitted that they managed to save a lot from avoiding the use of synthetic chemical inputs. Constitent with the conclusion of this study, Jour et al. (2013) reported that one good impact is that they can then spend the money saved for other purposes such as children's school matters, renovate their houses and most importantly they can allocate that saving for pilgrimage to Makkah. Interestingly, Jour et al. (2013) found that previously, when they still applied conventional farming system, every season they had to spend roughly RM 2,933 and after the switch to natural farming their spending fell to about RM 817. The first reduction is 72% which is when the community-based organization (CBO) slowly switching to natural farming methods (Jour et al., 2013). Followed by the second reduction is 90% whereas the CBO tried to minimize herbicides and eliminate additional fertilizer (Jour et al., 2013).

Based on the findings of this study and other cited research in this study, we can certainly conclude that a sustainable agriculture system is able to enhance the generation of local income while using local resources. In the long term run, sustainable agriculture system has potential to alleviate poverty among the main actors in the food supply chain in African and the sub-Saharan Africa (Jour et al., 2013). However, as Jour et al., (2013) pointed out, it is not easy to change and to prove the mentality of the most farmers who prefer with the conventional method who prefer short term gains at the expense of soil health and future low incomes. This is where the cohesion and synergy of multiple actors in the tea sector including the government and academia comes into place. It is very important for us to know is that the ability to cut costs on farming activities not only gives advantages to the farmers themselves but also reflect an improvement of food quality and social ties among local people (Jour et al., 2013).

Figure 15: Financial Feasibility of Tea Waste utilisation

Variables	Description	Tea Estates			Overall
		Lujeri	Bloomfield	Nsayama	
Area (Ha)		818	775	471	2064
Application Rate (Kg/Ha)		250	250	250	250
Amount of fertiliser applied (Kg)		204500	193750	117750	516000
Nutrient Content from T-Compound (Kg)	*N (24.69%)*	5049	47837	29073	127400
	P (5.21%)	10655	10095	6135	26884
	K (5.01%)	10246	9707	5900	25852
Amount T-Compund per Kg of N	*A Kg of N from T-Compound*	12.35	12.35	12.35	12.35
Amount of N per Ha from T-Compound	*5*12.35*	61.73	61.73	61.73	61.73
Price of 50Kg bag of T-compound (MK)	*Market price*	22500[3]	22500	22500	$34.62
Amount of nutrients in 50 Kg Bag of T-Compound	*N (24.69%)*	12.35	12.35	12.35	12.35
	P (5.21%)	2.61	2.61	2.61	2.61
	K (5.01%)	2.51	2.51	2.51	2.51
Nutrient Price per Kg for T-Compound (US$)	*N (24.69%)*	2.80	2.80	2.80	2.80
	P (5.21%)	13.28	13.28	13.28	13.28
	K (5.01%)	13.81	13.81	13.81	13.81
Amount of Tea waste (Kg)		374000	319000	192000	885000
Amount of Nutrients from Tea Waste Available	*N (3.19%)*	11931	10176	6125	28232
	P (0.58%)	2169	1850	1114	5133
	K (0.43%)	1608	1372	826	3806
Total cost of nitrogen from T-compound (US$)		141576.9	134134.6	81519.23	357230.8
Value of Nitrogen from Tea Waste (US$)	*Nitrogen-The basis*	33453.41	28533.79	17173.94	79161.14
Proportion	*Percentage*	23.6	21.3	21.1	22.2

[3] The market price of a 50Kg bag of T-compound fertilizer is MK22500.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The following conclusions are being made based on the study results:

The quantity of factory solid tea waste generated during tea processing have been found to be 885, 000kgs per single growing season which translates into 429kgs per hectare. The average proportions of nitrogen, phosphorus and potassium in tea waste have been found to be 3.19%, 0.58% and 0.43% respectively. Furthermore, these average proportions were found to be lower than the proportions that are contained in T-compound, the chemical fertilizer that is used in tea production which were found to be 24.82%, 5.02% and 5.00%. Tea waste can supply 22.2% of the total nitrogen content required for the production of tea translating into 22.2% cost saved. The findings presented highlight the substantial potential of utilizing tea waste in tea production as an environmentally friendly and cost-effective alternative to chemical fertilizers. The significant quantity of tea waste generated during processing, combined with its moderate nutrient content, suggests that it can be a valuable source of nitrogen, phosphorus, and potassium for tea plants. While the proportions of these nutrients in tea waste are lower than those in chemical fertilizers like T-compound, the study reveals that tea waste can still contribute 22.2% of the necessary nitrogen content for tea production. This not only demonstrates the resourcefulness of reusing waste in agricultural practices but also underscores its financial benefits. Embracing the utilization of tea waste could present a win-win situation, promoting sustainable tea cultivation, reducing waste generation, and positively impacting both economic and environmental aspects of tea production.

5.2 Recommendations

Based on the conclusions above, the study makes the following recommendations:

i. There is need to implement on-site composting facilities at tea processing factories to manage tea waste effectively. Composting can enhance the nutrient availability in tea waste and reduce potential pathogen risks, making it a safer and more effective organic fertilizer.

ii. There is need to develop a comprehensive fertilization strategy that combines tea waste with chemical fertilizers. This integrated approach can leverage the nitrogen, phosphorus, and potassium content in tea waste to supplement chemical fertilizers, thereby reducing overall fertilizer costs and enhancing soil health.

iii. Need to calculate precise application rates for tea waste to ensure the appropriate amount of nutrients are provided to the tea plants. Since tea waste supplies 22.2% of the required nitrogen, adjust the quantity of chemical fertilizers accordingly to prevent nutrient imbalances and optimize plant growth.

iv. There is need by agricultural extension services to raise awareness among tea farmers, processors, and stakeholders about the benefits of utilizing tea waste as a sustainable fertilizer as well as providing training and guidance on proper waste management practices and fertilizer application techniques.

v. The agricultural research team should conduct further field trials and research studies to assess the long-term effects of tea waste application on soil health, plant growth, and tea quality.

vi. There should be a need for comprehensive cost saving analysis to be done by the research team, data acquisition specialists and data analysts that factors in all the expenditure variables from both organic tea waste and inorganic fertilizer with significant testing to provide a more thorough assessment of the economic aspects and finding if there are any significant differences in the net profit and net yield from organic tea waste and inorganic fertilizer fields. This was a limitation in this study as some of the critical data for such analyses could not be accessed.

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APPENDICES

Appendix one: Raw Table for proximate analysis results

Table 1: Analysis of Nitrogen in Tea Waste

	Mass of sample	Dilution after digestion	Aliquot used	Concentration of acid (M)	Blank titer	Titer of acid (ml)	Nitrogen %
Sample Lujeri							
1a	0.5131	100	10	0.05	0	2.15	2.93
1b	0.5008	100	10	0.05	0	2.68	3.75
1c	0.5033	100	10	0.05	0	2.35	3.27
						Average	*3.32*
Sample Bloomfield							
1a	0.5518	100	10	0.05	0	2.54	3.22
1b	0.5361	100	10	0.05	0	2.38	3.11
1c	0.5003	100	10	0.05	0	2.22	3.11
						Average	*3.16*
Sample Nsayama							
1a	0.5118	100	10	0.05	0	2.3	3.15
1b	0.5361	100	10	0.05	0	2.13	2.78
1c	0.501	100	10	0.05	0	2.44	3.41
						Average	3.11
						Overall Average	3.19

Table 2: Analysis of Phosphorus in Tea Waste

Sample Identity	Mass of sample	Dilution after digestion (ml)	Volume used for analysis (ml)	Absorbance	Conce. *(ppm)*	Phosphorus Conce. (%)	Phosphorus (%)
Sample Lujeri							
1a	1.003	100	10	0.468	6059.74	0.605	0.606
1b	1.360	100	10	0.439	4192.13	0.419	0.419
1c	1.118	100	10	0.454	5273.80	0.527	0.527
						Average	0.5173
Sample Bloomfield							
1a	1.133	100	10	0.536	6143.90	0.614	0.614
1b	1.399	100	10	0.524	4864.33	0.486	0.486
1c	1.007	100	10	0.504	6499.95	0.650	0.650
Sample Nsayama						*Average*	0.583
1a	1.069	100	10	0.595	7228.51	0.723	0.723
1b	1.138	100	10	0.497	5671.83	0.567	0.567
1c	1.096	100	10	0.543	6434.26	0.643	0.643
						Average	0.6443
						Overall Average	0.581

Table 3: Analysis of potassium in Tea Waste

Sample ID	Sample Mass(g)	Dilution after digestion (mL)	Absorbance	Conc. *(ppm)*	potassium Conc. (%)	Conc. (%)
Sample Lujeri						
1a	1.311	100	0.396	4442.051	0.444	0.4442
1b	1.014	100	0.352	3948.49	0.395	0.3948
1c	1.022	100	0.428	4801.005	0.480	0.4801
	Average					0.4397
Sample Bloomfield						
1a	1.189	100	0.398	4464.486	0.446	0.4464
1b	1.036	100	0.429	4812.222	0.481	0.4812
1c	1.208	100	0.376	4217.705	0.422	0.4218
	Average					0.4498
Sample Nsayama						
1a	1.008	100	0.328	3679.275	0.368	0.3679
1b	1.236	100	0.339	3802.665	0.380	0.3803
1c	1.208	100	0.373	4184.053	0.418	0.4184
	Average					0.3889
	Overall Average					0.4261